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J952-66

SAFE SKIES
for Tomorrow

Aviation Safety in a Competitive Environment

CONGRESS OF THE UNITED STATES   OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

It has been 10 years since the Airline Deregulation Act of 1978 transformed the rules of the game for the commercial aviation industry. Although new entrants plunged into the market throughout the early 1980s, the industry had consolidated markedly by late 1987. While many of the major players remain the same, computerized reservation systems and hub and spoke scheduling have changed substantially the way airlines operate. Unquestionably, more Americans than ever are flying, and the safety record for commercial aviation in the United States remains among the best in the world. Nonetheless, even after many studies on the impacts of deregulation, questions linger about the adequacy of existing Federal safety policies and programs. The Committee on Public Works and Transportation and the Subcommittee on Government Activities and Transportation of the Government Operations Committee, both of the House of Representatives, asked the Office of Technology Assessment to determine how well existing safety policies, regulations, and technologies meet the government's responsibility for ensuring safety in commercial aviation. The study was endorsed by the Senate Committee on Commerce, Science, and Transportation.

This report contains the results of that analysis, and a review of critical management issues for the Federal Aviation Administration (FAA) has been added to the basic questions about the adequacy of Federal standards and programs. During the course of the study, it became clear that a full report for Congress would have to consider how policy is determined and implemented, and thus the operation of FAA and the role of the Department of Transportation. This comprehensive look at aviation safety also includes the economic framework of the industry as it affects operations, an analysis of safety data, and a review of research and development for safety technologies for both industry and government.

Throughout the study, the advisory panel, review group, workshop participants, and a host of contributors (see app. B) played key roles in developing the major issues and contributed a broad and invaluable range of perspectives. OTA thanks them for their substantial commitment of time and energy. Their participation does not necessarily represent endorsement of the contents of the report, for which OTA bears sole responsibility.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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CONTENTS

Page

CHAPTER 1: SUMMARY ... 3
Evaluating Safety in Times of Change ... 4
Safety Management ... 5
System Operating Improvements ... 7
Changes in the Safety System: Industry ... 12
Changes in the Safety System: FAA ... 15
  FAA Planning and Air Traffic System Management ... 16
  Personnel and Training ... 17
Technologies To Enhance Safety ... 18
  R&D Management ... 20
FAA Safety Data Programs ... 20

CHAPTER 2: AIRLINE ECONOMIC CONTEXT ... 25
Commercial Air Transportation—Major Changes ... 25
  Growth in the Industry ... 26
  Consolidations ... 27
  Aircraft Acquisition ... 29
  Regional Airlines ... 29
  Shift Away From Open Entry ... 31
  International Ties ... 32
Operational Changes ... 32
  Hub and Spoke Service ... 33
  Code-sharing ... 33
  Computerized Reservation Systems (CRS) ... 33
  Controlling Costs ... 34
Profit and Debt Trends ... 35
Policy Issues Related to Industry Changes ... 36
  Airport Capacity ... 36
  Demand Management ... 38
  Effects of Consolidations on Employees ... 39
  Federal Labor Policy Changes ... 39
Public Policies Affecting Airline Operations ... 40
  Air Traffic Controller Strike in 1981 ... 40
  Federal Budget Cutbacks and FAA Inspection Program ... 40
  Environmental Concerns ... 41
Conclusions ... 41

CHAPTER 3: REGULATORY AND INSTITUTIONAL FRAMEWORK ... 45
How It All Began ... 45
  Air Mail Service ... 45
  Early Safety Initiatives ... 46
  The Beginning of Economic Regulation ... 47
  An Expanding Federal Role ... 47
  Industry Expansion ... 48
  Responding to Industry Growth ... 48
  Airline Deregulation ... 50
Federal Aviation Safety Structure ... 52
  FAA Responsibility ... 52
  Other Federal Safety Roles ... 54
  FAA Funding ... 54
  Organizational Issues—System Safety Management ... 54
FAA Regulatory Program ... 56
  The Office of Airworthiness ... 56
  Office of Flight Standards ... 56
  Regulatory Program Issues ... 58

Page
Adequacy of FAA Minimum Standards 59
The FAA Rulemaking Process 59
Air Traffic Control Issues 60
FAA Technology Development Issues 61
Manpower and Training Needs 62
Airport Issues and Safety 62
Local Control of Airports 63
Airport Noise 63
Land Use Policies and Airport Capacity 64
Conclusions and Policy Options 65

CHAPTER 4: SAFETY MEASUREMENTS AND DATA RESOURCES 69
Measuring Transportation Safety 69
Safety Factors 69
Exposure Data 70
Nonaccident Safety Data 71
Primary Safety Factors 73
Secondary and Tertiary Safety Factors: Industry Safety Posture 75
Data Resources 77
Federal Safety Data Resources 77
FAA 77
National Transportation Safety Board 84
NASA 85
RSPA 86
Conclusions and Options 87

CHAPTER 5: AVIATION SAFETY DATA ANALYSIS 93
Accident Data 93
Accidents and Fatalities 93
Accident Causes and Types 95
Nonaccident Safety Data 98
Incident Data 98
Air Traffic Incidents 99
General Incidents 102
Accident/Incident Causal Factors 103
Aircraft Capabilities 103
Personnel Capabilities 105
Traffic Environment 105
Management Practices 105
Maintenance 106
Operations 108
Regional/Commuter Airline Operations 109
Employee Selection and Training 110
Management Policies 111
Conclusions and Policy Options 112

CHAPTER 6: HUMAN FACTORS IN COMMERCIAL AVIATION 117
Human Error 118
Preventing Errors 119
Compensating for Errors 120
Human Factors Data 120
Industry and Federal Roles in Human Factors 121
Growing Concerns 121
Federal Responsibilities 127
Industry Responsibilities 129
Labor's Role 131
Conclusions and Policy Options 131

Page
CHAPTER 7: AIR TRAFFIC SYSTEM TECHNOLOGIES 135
Elements of the Air Traffic System 135
  Models for Evaluating Changes to the Air Traffic System 135
  Airports 137
  Airspace 139
The National Airspace System Plan 139
  Air Traffic Control Hardware and Software 140
  TRACON Improvements 143
Training Air Traffic Controllers 146
Collision Avoidance Technology 147
  Ground Collision Avoidance 148
Communications 150
  Navigation 153
  Surveillance 154
Weather Technologies and Training 155
  Windshear 155
  National Weather Service 157
  Air Traffic Control Role 157
  Weather Research and Development 158
Liability Issues 159
Conclusions and Policy Options 159

CHAPTER 8: AIRCRAFT TECHNOLOGIES 165
Regulation of Aircraft Technologies 165
  Airworthiness 166
  Equipment Certification Process 167
  Simulators for Pilot and Mechanic Training 169
The Future of Commercial Aircraft Technology 170
  Cockpit Technologies 170
  Advanced Materials for Aircraft 171
  New Aircraft Engine Types 172
  Technologies and Training for Icing 174
  Crash and Fire Safety Technologies 175
Conclusions and Policy Options 175

APPENDIX A: LIST OF ACRONYMS 179
APPENDIX B: WORKSHOP PARTICIPANTS, REVIEWERS, AND CONTRIBUTORS 180

Boxes

Box *Page*
1-A. Commercial Aviation Safety Policy Options 6
2-A. Airport Scheduling Meetings 37
3-A. A Regulatory Enigma: When is a Commuter an Air Carrier and When is it an Air Taxi? 50
3-B. Overview of the FAA Regulatory Program 56
3-C. A Case Study: 747-400 Passenger Exit Doors 57
4-A. Measures of Transportation Safety: Definitions 73
6-A. Air Traffic Control Automation 125

Figures

Figure *Page*
1-1. Passenger Fatality Rates for Part 121 Scheduled Airlines 3
1-2. Total Operations at Towered Airports 7
1-3. Air Traffic Activity at Selected Hubs 8
1-4. Air Carrier Near-Midair Collisions 9
1-5. Accident Cause and Prevention Chain 11

Figure *Page*
1-6. Part 121 Total and Human Error-Caused Accidents 12
1-7. Average Flight Equipment Maintenance Expense for B727-200 Fleet 14
1-8. Basic In-Flight Rate, B727/JT8D Engines 15
2-1. Scheduled Airline Passengers 27
2-2. Air Traffic Activity at Selected Hubs 28
2-3. Large Aircraft in Commercial Service 29
2-4. Industry Market Share: Revenue Passenger-Miles 30
2-5. Expense Indicators of Major Airlines, 1978-1986: Labor and Maintenance 34
2-6. Net Profits of Major Airlines, 1986 36
4-1. Commercial Aviation Accident Causal and Preventive Factors 72
5-1. Passenger Fatality Rates for Part 121 Scheduled Airlines 93
5-2. Airline Accidents Initiated by Aircraft Equipment Failure 96
5-3. Part 121 Accident Broad Causes and Factors 96
5-4. Air Carrier Near Midair Collisions (1975-87) 100
5-5. Operations Per Controller at Towers and Centers 102
5-6. Basic In-flight Shutdown Rate, B727/JT8D Engines 104
5-7. Average Flight Equipment Maintenance Expense for B727-200 Fleet 107
6-1. Part 121 Total and Human Error-Caused Accidents 117
7-1. Air Traffic Control on a Typical Commercial Flight 141
7-2. Locations of Air Route Traffic Control Centers 142
7-3. Terminal Areas Where Radar Coverage is Provided 144
7-4. Locations of TRACONS With ARTS-IIIA and ARTS-IIIE Equipment 145
7-5. Locations of Airport Surface Detection Equipment Radars 150
7-6. Windshear Accidents and Incidents Before and After LLWAS Implementation 158
8-1. Controlled Flight Into Terrain: Descent and Approach Phases of Flight 166

Tables

Table *Page*
1-1. Commercial Aviation Accident and Fatality Rates 5
1-2. Part 121 Accident Causes 10
1-3. Qualifications of New-Hire Commercial Flight Crews 14
1-4. Selected FAA Employee Totals (1978-87) 17
2-1. Commercial Aviation Traffic Statistics, 1986 16
2-2. Regional Airline Revenue Passenger-Miles 30
2-3. Percentage of Passengers Enplaned by Airlines at Selected U.S. Airports 32
3-1. Selected FAA Employee Totals, 1978-87 52
4-1. Safety Measures and Exposure Parameters 71
4-2. Federal Aviation Safety Databases 78
5-1. Commercial Aviation Accident and Fatality Totals, 1975-1987 94
5-2. Commercial Aviation Accident and Fataltity Rates 94
5-3. Accident Categories 97
5-4. Part 121 Fatal Accidents, 1975-86 97
5-5. Part 121 Total Accidents, 1982-1985 98
5-6. Commercial Aircraft Midair Collisions 99
5-7. Qualifications of New-Hire Commercial Flight Crews 110
6-1. Significant Jetliner Accident Causes in 93 Major Accidents Worldwide (1977-1984) 117
7-1. Status of Major National Airspace System (NAS) Plan Projects 140

Chapter 1
Summary

Photo credit: The Singer Co.

Advanced technology cockpits are important to the aviation safety system.

CONTENTS

Page
Evaluating Safety in Times of Change 4
Safety Management 5
System Operating Improvements 7
Changes in the Safety System: Industry 12
Changes in the Safety System: FAA 15
  FAA Planning and Air Traffic System Management 16
  Personnel and Training 17
Technologies To Enhance Safety 18
  R&D Management 20
FAA Safety Data Programs 20

Box

Box *Page*
1-A. Commercial Aviation Safety Policy Options 6

Figures

Figure *Page*
1-1. Passenger Fatality Rates for Part 121 Scheduled Airlines 3
1-2. Total Operations at Towered Airports 7
1-3. Air Traffic Activity at Selected Hubs 8
1-4. Air Carrier Near-Midair Collisions 9
1-5. Accident Cause and Prevention Chain 11
1-6. Part 121 Total and Human Error-Caused Accidents 12
1-7. Average Flight Equipment Maintenance Expense for B727-200 Fleet 14
1-8. Basic In-Flight Rate, B727/JT8D Engines 15

Tables

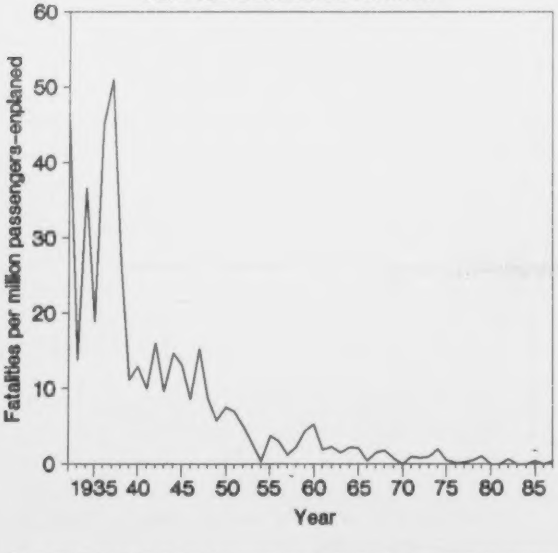
Table *Page*
1-1. Commercial Aviation Accident and Fatality Rates 5
1-2. Part 121 Accident Causes 10
1-3. Qualifications of New-Hire Commercial Flight Crews 14
1-4. Selected FAA Employee Totals (1978-87) 17

Chapter 1
Summary

Americans are a people both fascinated and frightened by flying. Thousands of U.S. citizens travel safely by air daily; air travelers numbered some 480 million in 1987, and lured by lower fares, passenger ranks have swelled by some 10 percent annually over the past 3 years. Yet no story about air travel seems too unimportant for media attention. Almost daily, newspaper stories chronicle the latest near midair collision (NMAC) or on-time and passenger complaint records. How well founded is the fear and how much of it is an outgrowth of the awe with which humans naturally view the marvel that flight represents?

Thanks to sustained and collective effort, the United States has achieved an aviation safety record that has continued to improve over time (see figure 1-1) and now ranks among the best in the world. Indeed, major passenger aircraft crashes are so infrequent that identifying aspects of the safety system that need modification requires thorough and wide-ranging research.

Figure 1-1.—Passenger Fatality Rates for Part 121 Scheduled Airlines[a]



[a] Part 121 scheduled airlines transport over 90 percent of commercial aviation passengers.

SOURCE: Office of Technology Assessment based on data compiled from the Civil Aeronautics Board, Federal Aviation Administration, and National Transportation Safety Board.

Countless, interrelated, and overlapping supports form the safety system for commercial aviation in the United States. Participants include the Federal Aviation Administration (FAA); the U.S. Department of Transportation (DOT); the airlines and related labor groups; the aircraft and equipment manufacturers; and the public's elected representatives—the U.S. Congress. Numerous other groups, including the National Transportation Safety Board (NTSB), the National Aeronautics and Space Administration (NASA), the National Weather Service, and a variety of consumer and industry safety advocates, also play important roles. Together, these groups form an aviation safety system that is exceedingly complex and effective—only a few hundred of the 2 million deaths in the United States annually are from commercial aviation accidents, a marked contrast to the tens of thousands of annual motor vehicle accident fatalities.

Pivotal members of this safety network, the airlines, each follow individual corporate philosophies, but have one common characteristic—during the past decade each has changed operating practices to control costs, eliminating some of the layers of the old safety system and replacing them with alternatives that must still be evaluated. While "safety comes first" is the instant response of airline executives when asked the basis for management decisions, this universal answer masks wide variances in airline corporate cultures and operating procedures. Safety first means one set of corporate guidelines to the airline that already owns adequate landing slots at a crowded airport and has ample financial reserves to purchase additional slots. It means something else entirely to a financially strapped airline that must choose between discretionary maintenance of its aircraft and purchase of additional airport slots, because it cannot afford both. These alternatives illustrate that each airline uses different parameters to make the choices necessary to satisfy customers with reliable, low-fare service and still make a profit in a fiercely competitive industry.[1]

---

[1] Information in this report on changes in the industry is drawn directly from OTA's primary research, including workshops, site visits, and conversations and correspondence with representatives of industry and the research community.

Media and congressional examination of passenger delays, on-time departures, and airline labor and maintenance practices are symptoms of the profound and rapid changes industry has undergone. Similar scrutiny of air traffic controller and inspector work force levels, tensions between DOT and FAA, and progress of the National Airspace System[2] (NAS) Plan are byproducts of national budget constraints, which have left FAA scrambling vainly to catch up with industry. Even after trouble spots have been pinpointed, Federal processes to put in place regulations, technologies, or programs as countermeasures are excessively time-consuming. Major changes in regulations, such as requirements for ground proximity warning systems or collision avoidance devices, usually occur only in the shocked and saddened aftermath of a major airline accident, even though the underlying causal problems were recognized years earlier.

EVALUATING SAFETY IN TIMES OF CHANGE

Before passage of the Airline Deregulation Act (ADA) in 1978, the commercial airline industry was relatively stable. Industry changes occurred slowly, a constant group of carriers competed for the travel dollar, and the costs of required safety improvements could be passed quickly to the consumer. ADA removed Federal controls over routes, fares, and new entries to encourage competition, but left unaltered FAA's responsibility for commercial aviation safety. Events of the past decade have shown that neither Congress nor the executive branch fully comprehended the complexity of overseeing and regulating a newly competitive industry.

To determine how changes in airline operations after deregulation affected air safety and what steps the Federal Government could take to ensure safe skies for tomorrow, OTA took a comprehensive look at the entire commercial air safety system. The first step included a review of FAA safety operations and program areas, including technology development and training. This was followed by review and analysis of safety-related data from all available government and industry sources. The final component was identifying and assessing the changes in industry practices that have occurred over the past decade in the wake of economic deregulation. Financial data from the large and small airlines and information from the industry, collected on a confidential basis by OTA, were the major resources tapped.

Aggregate accident data show that the number of accidents for large airlines has held steady and has declined slightly for small airlines in the decade since deregulation (see table 1-1). However, growth in commercial air travel and the dominance of hub and spoke operations have changed airline and air traffic operations, in some cases dramatically. Vigorous Federal safety management programs and technical and operational oversight are vital to ensuring a high level of public safety, especially in a period of major upheaval. FAA, hard hit by budget cuts and personnel reductions, has fallen behind in both numbers of staff and levels of technical expertise.

OTA identified two key areas for enhancing air safety:

- **safety management improvements, including streamlining FAA's internal organization, increasing inspector and operating work forces, raising levels of expertise, and establishing the primacy of FAA's safety responsibilities to ensure a more powerful system safety program; and**
- **system operating improvements, including expanding air traffic control (ATC) capacity and capability; enhancing human performance; and upgrading weather forecasting, detection, and dissemination and air/ground communications.**

---

[2] The National Airspace System Plan is a loose grouping of long-term technology improvements for the Federal Government's operations of the airways and air traffic control. Components include (among others) the Advanced Automation System for air traffic, Doppler weather radar, and the Microwave Landing System.

Table 1-1.—Commercial Aviation Accident and Fatality Rates

Year	Part 121 (scheduled)	Part 121 (nonscheduled)	Part 135[a] (scheduled)	Part 135[b] (nonscheduled)
Accidents per million departures:				
75-77	4.8	53	27	58
78-80	3.7	39	27	54
81-83	4.1	18	12	55
84-86	2.8	22	8	53
87	4.3	23	14	38
75-87	3.8	30	17	54
Fatal accidents per million departures:				
75-77	0.48	10.6	6.3	11
78-80	0.57	6.5	6.5	13
81-83	0.72	2.6	2.6	13
84-86	0.34	8.0	2.1	11
87	0.43	4.6	4.1	12
75-87	0.51	6.5	4.1	12
Fatalities per million passengers-enplaned:[c]				
75-77	0.34	24.2	3.4	14
78-80	0.56	0.2	4.4	13
81-83	0.26	0.1	1.5	11
84-86	0.17	14.7	1.6	9
87	0.41	0.1	2.8	10
75-87	0.33	9.1	2.6	12

[a] Scheduled Part 135 passenger counts estimated by OTA based on Regional Airline Association data.

[b] Nonscheduled Part 135 passenger and departure data estimated by OTA based on National Air Transportation Association and other air taxi data.

[c] OTA calculations based on National Transportation Safety Board and Federal Aviation Administration data. All 1987 rates based on estimated passenger-enplanement data.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988, unless otherwise noted.

SAFETY MANAGEMENT

FAA has a dual mandate: ". . . to promote safety of flight . . . in air commerce through standard setting . . ." and to carry out for the Secretary of Transportation the responsibility ". . . to encourage and foster the development of air commerce."[3] While these tasks are not necessarily incompatible, an inherent tension exists between them in two vital safety activities of FAA—inspections, and managing and operating ATC. In times of massive change and rapid travel growth, such as the past decade, fulfilling both goals of the mandate presents the agency with unavoidable conflicts. The pressures on the air traffic system of airline schedules bunched at peak hours provide one obvious example. **OTA concludes that if Congress wishes safety to be preeminent in FAA's mandate, it may wish to make that explicit.**

OTA analysis indicates that many FAA safety functions need strengthening. Among the most important are raising inspection and air traffic personnel levels; near-term improvements to ATC to cope with increased traffic; analytic tools for managing airport and airspace demand; training programs for inspectors, controllers, and technicians; programs

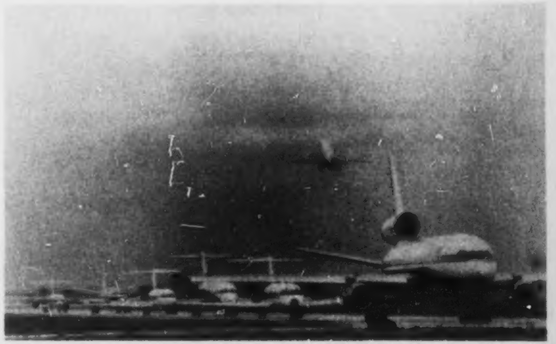


Photo credit: Federal Aviation Administration

Heavy traffic places extra demands on air traffic control and the aviation safety system.

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[3] Public Law 85-726.

and systems for tracking and analyzing safety data; and long-range system planning.

Furthermore, FAA could recognize system safety management as a specific goal and refocus existing programs accordingly. For example, new emphasis could be placed on systematic and regular monitoring of financial conditions and management changes at airlines, realistic life-cycle planning for costs and personnel for the NAS Plan, and vigorous programs in hazard and human factors analysis for new technologies. **OTA concludes that additional, stable funding resources to support these functions and FAA policy and resource management, technical competence, and system safety oversight will be needed.** A rough analysis of programs and funding needs may be found in box 1-A.

Improvements will not be sufficient if made piecemeal, however, because the safety functions of FAA are so closely interrelated. **OTA concludes that FAA's functions cannot be separated into regulatory and operating (ATC) components without diminishing the effectiveness of the entire system. Furthermore, without more emphasis on system safety at the very top, FAA agency-wide problems that have hampered the organization's capabilities are likely to continue.** Moreover, FAA organizational problems have exacerbated the impacts on the agency of government-wide problems of inefficient Federal personnel and procurement requirements and national budget constraints and priorities.

Management changes are needed that increase and support long-range planning; technical capabilities; internal coordination, especially between research and development (R&D) activities and ongoing operations; even-handed application of regulations in inspections, enforcement, and certification across regions; and management information systems. Shortcomings in these activities are embedded in the FAA structure and operations and

Box 1-A.—Commercial Aviation Safety Policy Options

Policy option	Maintain current safety with increased demand	Increase safety	Approximate costs ($ millions) Fixed	Approximate costs ($ millions) Recurring
FAA management improvements:				
1. Make safety FAA's preeminent responsibility	X	X	<1	<1
2. Lengthen and stabilize term of Administrator	X	X	<1	<1
3. Streamline FAA organization	X	X	1	1
4. Increase inspector staffing	X	X	<1	60
5. Address personnel issues of relocation, technical expertise, and compensation	X		5	40
6. Improve training programs for field and facility personnel	X		80	20
7. Improve data collection and analysis	X		1	5
System operating improvements:				
1. Near-term ATC improvements	X		200	2
2. Controller and technician staffing	X		<1	300
3. Manage airport and airspace demand; develop system capacity models	X		20	2
4. Undertake human factors research and incorporate into procedures and regulations	X	X	20	5
5. Enhance hazardous weather safety and communications	X	X	80	<1
Total			350-450	400-500

KEY: FAA = Federal Aviation Administration; < = less than; ATC = air traffic control.
NOTE: FAA 1988 Appropriation = $6.1 billion.

SOURCE: Office of Technology Assessment, 1988.

affect air traffic operations, technology development, and safety standards programs alike.

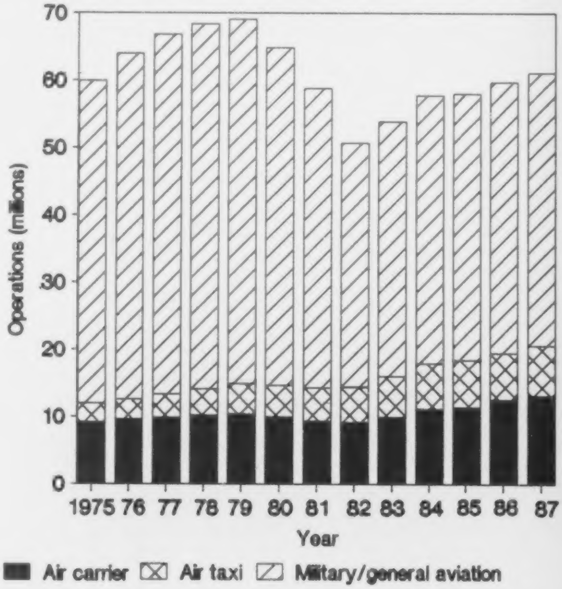
The most striking improvement in FAA operations and regulatory and oversight programs would result from the establishment of strong, independent, and consistent leadership by the FAA Administrator. **Congress may wish to consider three far-reaching changes to bring about this goal:**

- **establishing the preeminence of the safety function in FAA's mandate, holding the Administrator accountable solely for safety, and allocating stable and adequate funding resources from the General Fund and the Airport and Airway Trust Fund;**
- **streamlining the structure of FAA to give the Administrator direct control of the far-flung organization and to permit holding subordinates accountable for system safety; and**
- **increasing the Administrator's length of tenure to a fixed term, perhaps up to 5 years. To provide accountability, Congress may wish to require the Administrator to develop a rolling 5-year agency development plan and report annually on its status.**

SYSTEM OPERATING IMPROVEMENTS

Commercial air transportation operations (takeoffs and landings) at U.S. airports with FAA control towers have reached record levels each year since 1984, with commuters and air taxis accounting for one-third of those flights.[4] Due to declines in general aviation (GA) activity across the country, total traffic nationwide is still below the peak of 69 million operations reached in 1979 (see figure 1-2). Although GA and military flights generate a large volume of traffic nationwide, they represent only a fraction of the operations at the largest and busiest airports—less than 6 percent at Chicago O'Hare and Atlanta Hartsfield, for example. While GA (and some military aircraft) share the facilities, air carrier operations account for most increases in operations at major airports (see figure 1-3).

Figure 1-2.—Total Operations at Towered Airports



SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

The good news is that more people can afford to fly. But increased traffic does strain industry, airport, and ATC equipment and personnel, requiring them to perform consistently at peak ability—a requirement they are often ill-equipped to meet. Strains are visible in the form of travel delays at some airports even in good weather, due to air traffic and airport congestion, equipment malfunction, and occasionally aircraft and ground crew shortages. Plans to build more runways and modernize airports have been stymied by interjurisdictional disputes over noise and land use that are unlikely to be resolved in the near term. ATC system renewal has moved at glacial speed, slowed by inadequate system planning, technology development difficulties, and administration and congressional budget decisions.

OTA found that increases in commercial air traffic correspond closely to the rise in reported NMACs

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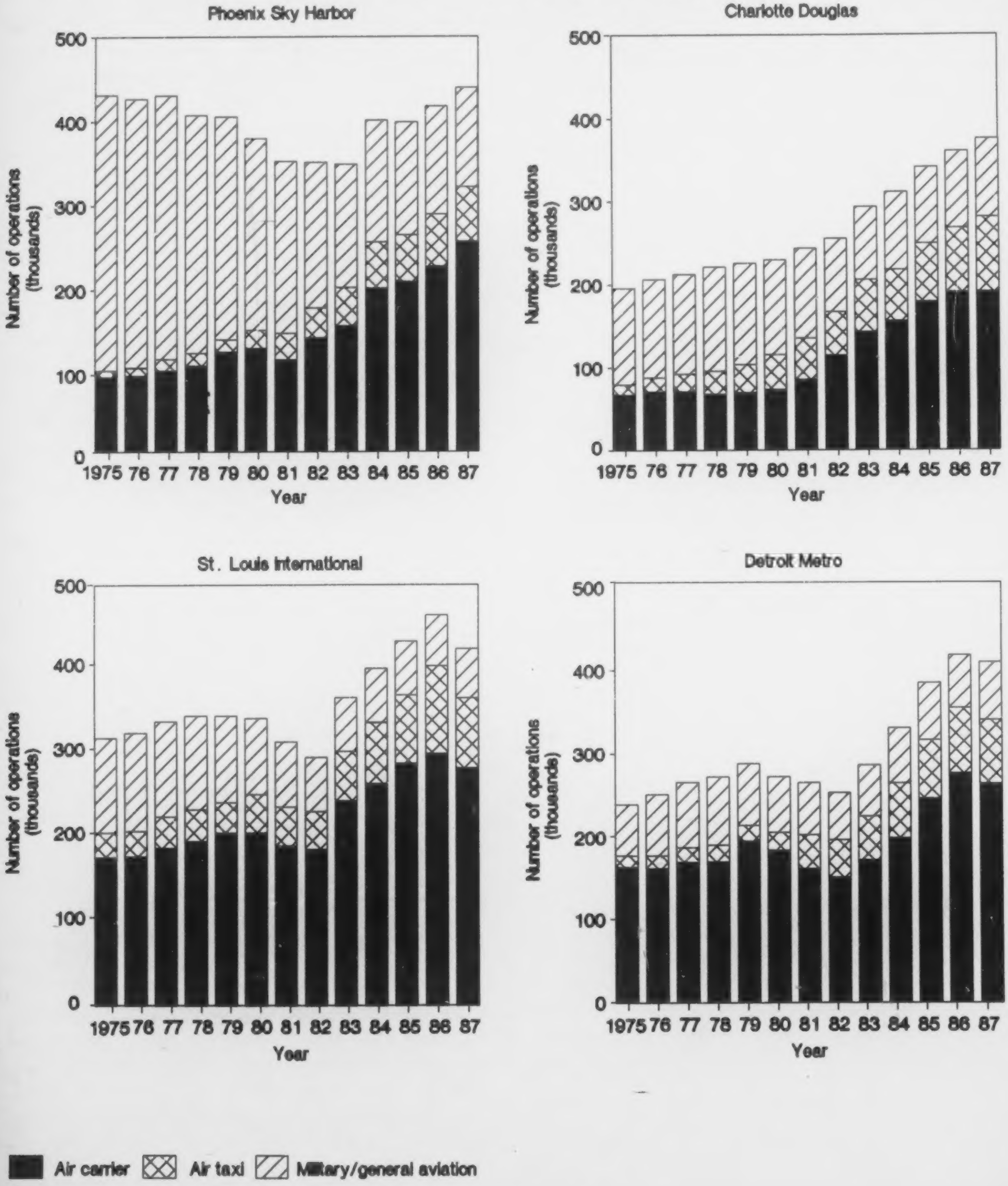
[4] Air traffic controllers, who record data on traffic operations, do not differentiate commuters from air taxis or Part 121 commuters from Part 135 commuters. Additionally, since many air taxis are similar to general aviation aircraft, an air taxi operation probably will not be counted as such unless it is so indicated in the flight plan. Therefore, air taxi operations are most likely underestimated by these statistics.

Figure 1-3.—Air Traffic Activity at Selected Hubs



SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

Photo credit: Federal Aviation Administration

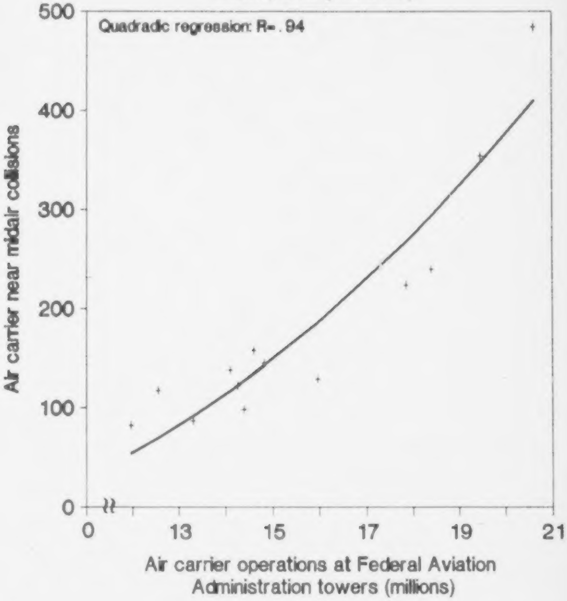
While they share the airspace with commercial airlines, general aviation planes make up only a fraction of the flights at the Nation's busiest airports.

involving commercial aircraft (see figure 1-4). While air traffic-related accidents are quite rare, and midair collisions show no trends, rising NMAC reports suggest that future growth in commercial traffic is a cause for concern. **OTA concludes that continued vigorous air traffic growth and increased traffic densities at more airports could outstrip the capabilities of the traffic system. Without immediate steps to modernize the ATC system and to manage air traffic flow and demand as necessary, present safety levels may not be sustainable.**

However, decisions about managing demand have major economic consequences for airlines—spelling success or failure for some small commuter airlines or large airlines in precarious financial condition. Such decisions thus pose serious equity issues and require careful scrutiny, public debate, and cooperative, deliberate decisionmaking backed by sound technical analysis.

Accidents usually result from a combination of failures occurring sequentially, or on occasion, simultaneously in one or more activities (see figure 1-5). Commercial flight safety requires that many varied activities be carried out without major error. Human error, severe weather, aircraft component failure, and limitations of the air traffic environment are the four primary causal factors in aviation accidents (see table 1-2).

Figure 1-4.—Air Carrier Near Midair Collisions (1975-87)



SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

OTA analyses of data from FAA, NTSB, airlines, and aircraft manufacturers confirmed that human error is at least partially responsible for over 65 percent of accidents, a percentage that has held constant over the past decade (see figure 1-6). Moreover, aircraft component failures, factors in over 40 percent of all accidents, are often compounded by human error, and weather-related accidents often involve faulty decisionmaking or communication.

OTA concludes that long-term improvements in aviation safety will come primarily from human-factors solutions, and that such solutions will be found through consistent, long-term support for R&D, analysis, and applications. Moreover, current FAA programs to understand human error and enhance controller, mechanic, and cockpit crew performance are inadequate. Data on reliability of human performance are difficult to collect, however, and causes of human error are not fully understood. The traffic environment, aircraft design, and management practices directly influence human performance, and recent changes in aircraft technology and operating practices have widespread implications that require extensive research. Human-factors hazard analyses, such as studies to determine whether people can operate new technologies quick-

Table 1-2.—Part 121 Accident Causes

	Fatal accidents (1975-86)	Fatal accidents (by percent[a])	Total accidents (1982-85)	Total accidents (by percent[a])
Initiating causal factor:				
Pilot	15	43	23	46
Personnel	5[b]	14	4[c]	8
Aircraft	9	26	18	36
Weather	3	9	2	4
Miscellaneous	3[d]	9	3[e]	6
All causal factors:[f]				
Pilot	20	57	27	54
Personnel	5	14	4	8
Aircraft	12	34	23	46
Weather	9	26	11	22
Miscellaneous	3	9	3	6
Total accidents	35		50	

NOTE: Accidents involving weather turbulence, sabotage, or nonoperational events, such as ramp activities, are not included.

[a] Initiating causal factors may not total 100 percent due to rounding. For all causal factors, numbers do not total 100 percent, because most accidents involve multiple causes.

[b] Three accidents involving air traffic control personnel, one involving maintenance personnel, and one involving the pilot of another aircraft.

[c] Two accidents involving air traffic control personnel and two involving maintenance personnel.

[d] Two midair collisions, including Aeromexico DC-9/PA 28-181 over Cerritos, CA on Aug. 31, 1986, and one in-flight collision with a parachutist.

[e] Two collisions with birds and one collision while taxiing.

[f] All causal factors includes up to two significant causes in the sequence of events leading to the accident.

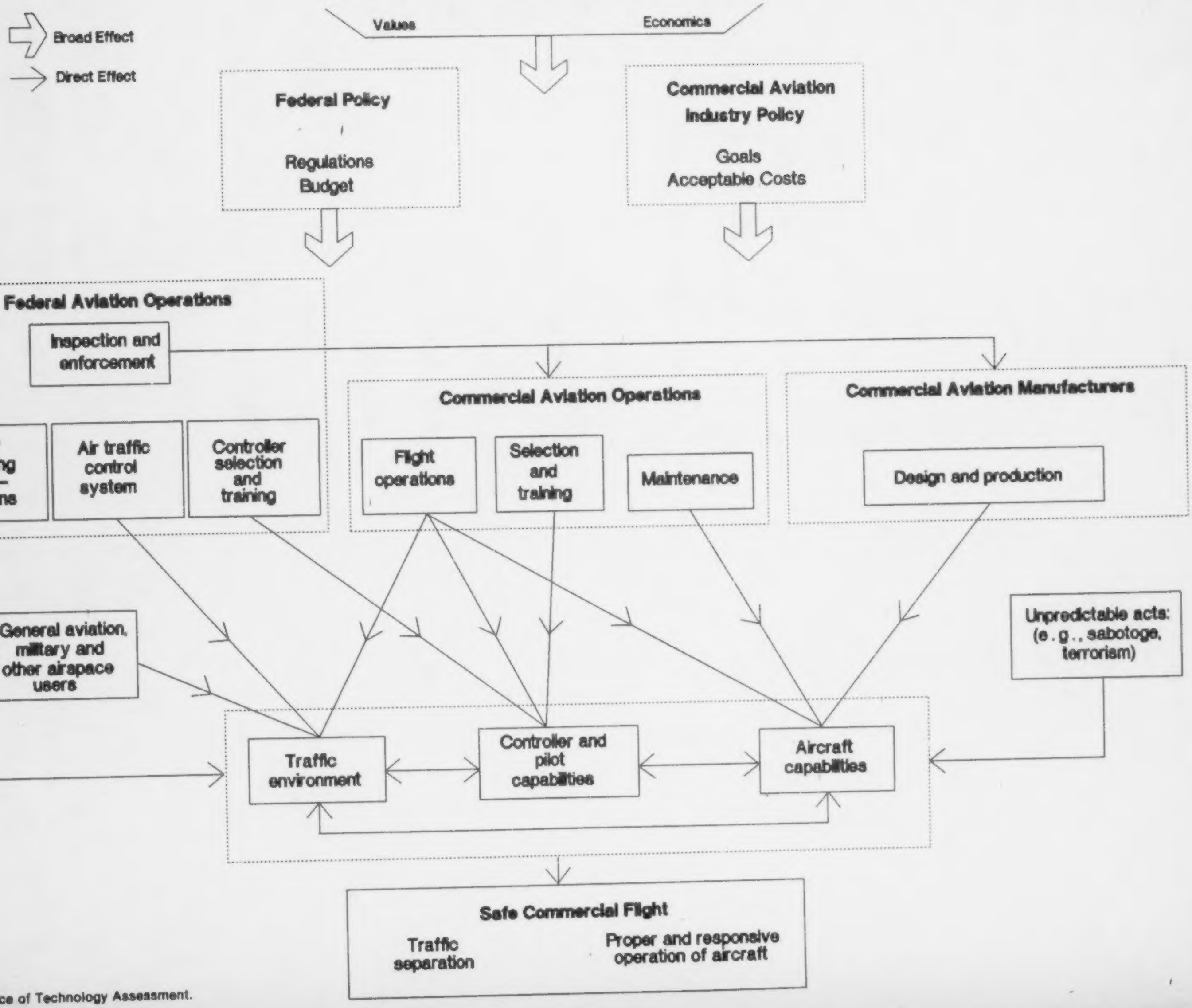
SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988.

ly and accurately in an emergency, are not presently a normal part of aircraft or ATC system design or certification. Such studies are vitally important as future technologies are introduced. Automation, pilot and controller selection and training, and the effects of management practices are specifically in need of attention.

In the short term, existing resources and understanding of human factors at NASA, the Department of Defense, universities, and industry could be utilized. FAA could request assistance from these groups to provide guidance for developing and disseminating explicit training procedures for upgrading crew coordination and decisionmaking. In the longer term, **Congress may wish to consider making human factors a core research technology and direct FAA to designate management resources for a research program. An FAA program that utilizes available human-factors expertise at NASA and other organizations to carry out fundamental work in this area could bring improvements to safety without large expenditures of additional funds.**

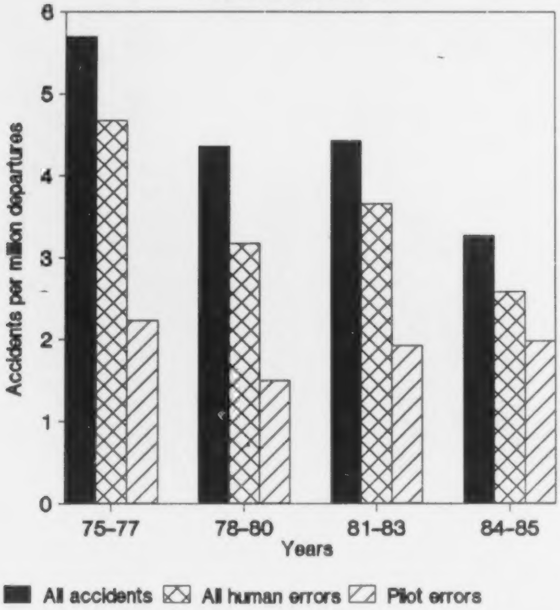
While technological progress has contributed greatly to advances in air safety, further improvements through technology will come at relatively higher cost. Nonetheless, **OTA concludes that technologies to improve prediction, detection, and interpretation of severe weather and for communicating and coordinating this information between ATC and the cockpit could contribute substantially to greater safety.** In particular, FAA commitment to rapid integration of modern, digital air/ground communications, augmented by appropriate automation, could increase both safety and efficiency.

Figure 1-5.—Accident Cause and Prevention Chain


Broad Effect
Direct Effect
Values
Economics
Federal Policy
Regulations
Budget
Commercial Aviation Industry Policy
Goals
Acceptable Costs
Federal Aviation Operations
Inspection and enforcement
Weather forecasting and communications
Air traffic control system
Controller selection and training
Commercial Aviation Operations
Flight operations
Selection and training
Maintenance
Commercial Aviation Manufacturers
Design and production
Weather
General aviation, military and other airspace users
Unpredictable acts: (e.g., sabotoge, terrorism)
Traffic environment
Controller and pilot capabilities
Aircraft capabilities
Safe Commercial Flight
Traffic separation
Proper and responsive operation of aircraft

SOURCE: Office of Technology Assessment.

Figure 1-6.—Part 121 Total and Human Error-Caused Accidents



SOURCE: Office of Technology Assessment based on National Transportation Safety Board data, 1975-85. Data from 1986 and 1987 are not yet available.

CHANGES IN THE SAFETY SYSTEM: INDUSTRY

Commercial aviation includes flights by scheduled large jetliners, smaller commuter planes, and air taxis, as well as cargo and charter jet service. Each industry segment has substantially different safety and economic effects on the aviation system. For convenience, OTA will refer to airlines as major (large) or commuter (regional). In practice, however, the divisions under the regulations are far from being so simple (for details see box 3-A in ch. 3). The formal designations for these airlines are:

- Major or large—14 CFR Part 121—operations of aircraft with more than 30 seats or 7,500 payload-pounds. Part 121 airlines carried 95 percent of passengers and accounted for 99 percent of revenue passenger-miles in 1986.
- Commuter—14 CFR Part 135—operations of aircraft with 30 seats or fewer. Part 135 commuter[5] airlines transported 4 percent of passengers, and air taxis accounted for only 1 percent.

Photo credit: Fokker Aircraft USA, Inc.

Some commuter airlines, such as this one, adhere to the same operating and airworthiness standards as large jetliners.

The single most significant change in large airline operations over the past decade has been the almost universal shift to hub-and-spoke operations that enable airlines to dominate their most successful markets. To retain connecting passengers, the major airlines have made arrangements with regional and commuter lines that feed passengers from small communities to their hubs to share identification codes on computerized reservations systems—a practice known as code-sharing. Where the performance of the commuter line is less than satisfactory, or where a chance exists that a head-to-head competitor at the hub may make a more favorable code-sharing arrangement, the major line is likely to buy the commuter outright. Of the 50 largest regional airlines that existed as independent entities several years ago, only 2 now remain unattached to a larger airline. Through hub dominance, the power of computerized reservation system booking, and code-sharing arrangements, the airline industry in 1988 is virtually closed to new entrants, except for carriers specializing in specific market niches.

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[5] These definitions can be confusing; some portions of the Federal Code apply the terms "commuter" or "regional" to scheduled operations of aircraft with 60 seats or fewer. Accident statistics show that the largest commuter airlines are as safe as the major carriers.

However, competition for passengers remains keen and economic pressures on carriers are intense. OTA research indicates that while airline officials are concerned about safety, financial considerations drive many industry decisions and will continue to do so as long as strong competition exists among the airlines. Primary decisionmakers at today's airlines do not always have the same understanding of operations that permeates management decisions made by experienced officials dedicated to safety.

Many factors related to enlarging market share and hub scheduling have affected industry's struggle to modernize and restructure. OTA identified the following as particularly difficult problem areas.

- Lag time between airlines' restructuring to capture market share and commensurate changes in their safety procedures. Hub-and-spoke operations require tight turnaround schedules, leaving little time for minor maintenance tasks during the day. Such operations also require airlines either to arrange for adequate maintenance capability at the spoke ends of their operations or to fly the aircraft back to a maintenance facility at night for repair. Some airlines contract with other carriers that have crews and parts available at spoke points; some redeploy their own personnel. If flying an ailing aircraft back to a hub is not feasible, other carriers charter aircraft and fly parts and mechanics to remote sites when necessary.

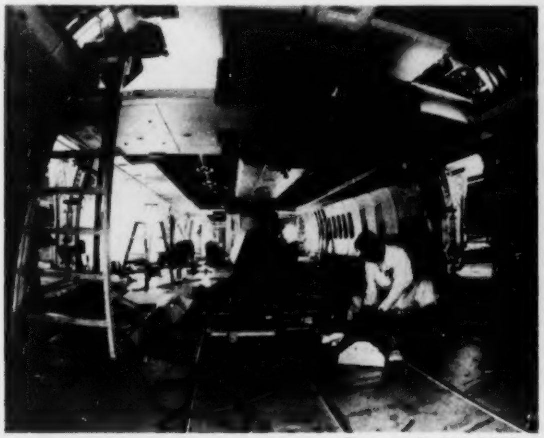


Photo credit: United Airlines

Careful attention to detail by airline maintenance personnel and Federal inspectors is essential to ensure system safety.

- As airlines merge or expand rapidly, they acquire or purchase used equipment, often aircraft different from those in their existing fleet. Some airlines choose to contract maintenance for planes that differ from the majority in their fleets. For other companies, repositioning and retraining maintenance personnel and rearranging equipment and inventory takes time and planning. Few airlines understood ahead of time how much care and advance planning would be required for these changes in their ground operations.
- Every airline has made differing and substantial structural changes to improve economic efficiency, although each company vigorously denies compromising safety by the alterations it has made. To lower costs some airlines have reduced planning and engineering departments, while others have pared back safety departments. Others eliminated weather or meteorology sections or began to make discretionary maintenance spending decisions based on the tightness of the budget. So long as airlines comply with minimum Federal standards, FAA has no grounds for questioning these types of decisions.
- Mergers have caused substantial industry readjustments; in some cases, flight crews have had to learn entirely new procedures. FAA does not

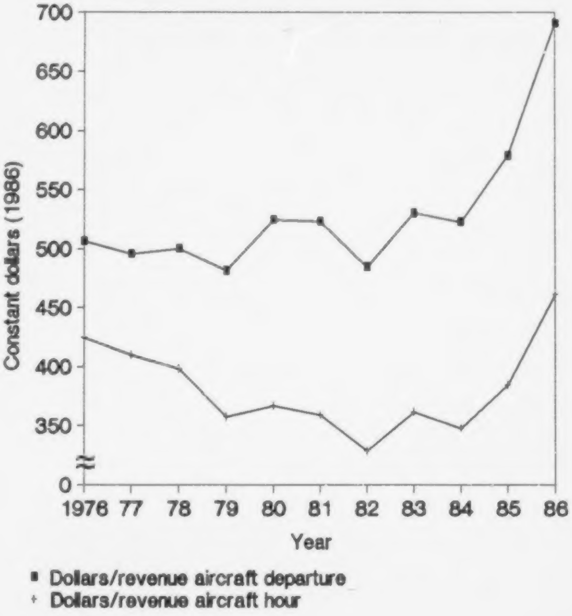
have human factors expertise to monitor or predict the impact of such changes on pilot performance, and Federal regulations are silent on methods to assist airline personnel through the difficulties inherent in a merger. Finally, while many small commuter airlines remain independent, numerous regional airlines now operate as adjuncts to major carriers. Only a few of the major airlines have taken steps to bolster the safety of their commuter lines by assisting with pilot and mechanic training.

- Many airlines have hired large numbers of flight and maintenance personnel to meet shortages caused by retirements and increases in air travel. While larger airlines have been able to keep experience levels high by hiring recently retired military pilots or pilots from smaller airlines, commuter airlines find themselves used as training grounds for larger carriers, which offer higher salaries and opportunities to fly jet aircraft. Several commuter carriers told OTA that they are experiencing over 100 percent turnover annually in their pilot ranks. Training facilities and programs are stretched, and experience levels in some of the major airlines and many of the regional and commuter lines have declined. Many regional airlines must hire pilots with little or no jet experience and limited flying hours (see table 1-3).

Airline management practices are an important control valve for commercial aviation safety, and airlines have always had different approaches to managing their operations. For example, while some airlines are reducing or eliminating safety, weather, or medical departments, other airlines with excellent safety records have never had such departments, preferring other safety management approaches. Some airlines are leasing aircraft and contracting maintenance, finding these procedures to be cost-effective. Moreover, OTA analysis showed increased spending for maintenance (in constant dollars) across the industry (see figure 1-7) during the past 5 years and no deterioration in aircraft reliability. (See figure 1-8 for an example.)

OTA finds that many airlines have lowered hiring standards, increased pilot and mechanic duty time, shifted to leased aircraft, and reorganized and cut wages. However, the cumulative impacts on safety of these decisions are difficult to quantify. Compensating activities in other parts of the system may counterbalance safety impacts of these actions. For example, FAA concentrated its oversight activities in the National Air Transportation

Figure 1-7.—Average Flight Equipment Maintenance Expense for B727-200 Fleet[a]



[a] Major carriers only.

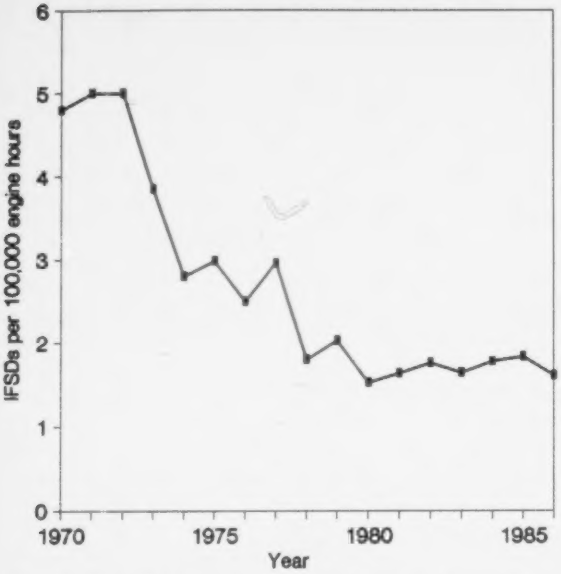
SOURCE: Office of Technology Assessment based on Research and Special Programs Administration data.

Table 1-3.—Qualifications of New-Hire Commercial Flight Crews (percent, by year)

	Major airlines		National airlines		Other jet airlines		Regional airlines	
Pilots with	1983	1986	1983	1986	1983	1986	1983	1986
Less than 2,000 hours total flight time	1	13	0	11	14	12	9	29
No military experience	46	56	18	66	55	70	83	88
No jet or turboprop flight time	1	2	1	6	24	29	32	28
No air transport pilot certificate and no flight engineer certificate	18	26	24	41	42	56	77	76

SOURCE: Office of Technology Assessment based on Future Aviation Professionals of America data, as of May 1987.

Figure 1-8.—Basic In-flight Shutdown (IFSD) Rate, (domestic operators only) B727/JT8D Engines



SOURCE: Office of Technology Assessment based on Boeing Commercial Airplane Co. data.

Inspection program in 1984. The inspections showed that airlines undergoing management turmoil tend to overlook details of safety programs. Since 1984, FAA has monitored selected airlines as closely as possible, given the limited numbers of trained inspectors. Large fines have occasionally resulted from these FAA activities, and airlines have subsequently upgraded safety procedures and recordkeeping.[6]

Some airlines have complained that FAA surveillance involves looking at a paper trail only, ignoring the fact that paper records are vital management tools as well as the major enforcement mechanism for FAA. Short aircraft turnaround times increase dependence on records; a 20-minute time period between pull up at the gate and departure leaves insufficient time for a thorough FAA inspection (not to mention repairs by mechanics). Under such circumstances, the aircraft logbook is an indispensable record of maintenance activities for airline personnel and FAA alike.

Limited Federal resources preclude frequent surprise inspections or indepth, continuous inspections, except on a special basis. **OTA concludes that vigilant FAA oversight of airline management procedures through unannounced inspections and periodic indepth audits of every large and small airline are indispensable tools for ensuring public safety. Based on operating and marketing changes now underway, the commuter industry warrants extensive and intensive FAA oversight during the shakeout expected over the next few years.** The special FAA inspection effort for commuters announced in early 1988 is a step in the right direction. However, it has forced postponement of several major carrier inspections, because FAA does not have enough inspectors to do both.

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[6] U.S. Department of Transportation, "National Air Transportation Inspection Program: Federal Aviation Administration, Mar. 4, 1984 - June 5, 1984," Report for the Secretary, unpublished typescript.

CHANGES IN THE SAFETY SYSTEM: FAA

Since Congress dismantled the Civil Aeronautics Board, FAA has been the chief regulator of the U.S. airline industry, with some political and analytic support from other parts of DOT. The task is formidable. On the one hand, the agency must stand up to intense pressure from DOT and industry on proposed regulatory and programmatic changes, and, on the other, address constant public and congressional anxieties about safety and convenience. Moreover, local governments play roles in determining airport operations and development that often conflict with FAA goals. Over the past several years, public attention has again focused sharply on whether FAA has the institutional capability and resources to carry out its operating, standard setting, rulemaking, and technology development functions effectively and guarantee compliance through its inspection programs.

Over the past decade, FAA's effectiveness has been undercut by administration policy decisions carried out by DOT and by national budget constraints entirely external to FAA activities. These have slowed FAA regulatory processes and procurement, limited the size of the inspection, ATC, and facilities technician work forces, eliminated many expert technical personnel who chose to seek more rewarding jobs in industry, and prevented modernization of equipment. Agency training programs, technical and human factors R&D, and long-range comprehensive planning have been especially hard hit.

-Only an agency with strong leadership and singleness of purpose and responsibility could maintain a steady course under such opposing pressures, and at FAA, such pressures only magnify internal management and structural shortcomings. The agency's organization is extraordinarily decentralized, making turf battles inevitable among the 22 top managers reporting to the Administrator. Rapid turnover in Administrators, common in executive branch agencies, has made such internal disagreements especially destructive. For example, although policy nominally originates from FAA headquarters, FAA standards for certification are not uniformly interpreted across regions. In at least one instance—exit doors for the Boeing 747 aircraft—the responsible region's ruling was effectively overturned by the Administrator, who wrote to the airlines, asking them not to use the eight-door configuration approved by the region.

OTA finds that while the autonomy of the regions permits allocation of personnel according to regional need, policy guidance to FAA regions from headquarters is inadequate to ensure nationally consistent standards. Lack of strong top management, inadequate comprehensive planning, and diminished technical expertise have led on occasion to budget and regulatory priorities being set for FAA through pressure on Congress or DOT policy officials by potent and vocal special interest groups. Appropriate consideration of system safety is not always part of this process.

Despite these deficiencies in the organization, FAA staff members at all levels are dedicated to aviation and to their operational and technical missions. However, these characteristics do not always lend themselves to full appreciation for intergovernmental issues, such as local land use decisions, environmental problems associated with airport construction, or complaints about airline schedule reliability. **OTA concludes that many decisions affecting aviation policy require participation by public officials at all governmental levels, ranging from Congress to local airport authorities. Such decisions cannot be made solely by FAA, an organization heavily reliant on technical and industry expertise.**

FAA Planning and Air Traffic System Management

An essential support for system safety management is an agency-wide comprehensive planning capability that includes participation by all major FAA programs in setting long-term safety goals and budget priorities to achieve them. Coupled with firm, consistent, top-level guidance, an agency-wide plan could ease conflicts between and among Associate Administrators and Regional Office Directors. Lack of such planning capability has created substantial difficulties for ATC programs.

In the best of times, airport and ATC issues create tension for FAA between ensuring the maximum traffic flow desired by industry, meeting safety standards, and considering State or local environmental and land use concerns. In its 1988 reauthorization of the Airport and Airway Trust Fund, Congress reaffirmed the importance of environmental concerns by increasing funding to airport authorities for land purchases. Such concerns are serious obstacles to near-term airport construction or expansion; we may have to live with existing airports for some years.

The air traffic system has many individual, interdependent components, and each one affects the safety and capacity of the overall system. Significant components affecting capacity of the current air traffic system are:

- airports;
- air route structure;
- the ATC system, including hardware, software and the humans who operate the system; and
- communications.

Any increase or decrease in capacity in one part of the system (e.g., airports) requires adjustments to the other parts to stabilize overall system capacity.

FAA badly needs effective tools for evaluating airport and airspace capacity and devising methods for increasing system capacity. At present, for example, weather technologies are used by Central Flow Control to determine capacity for airports. Aircraft are held on the ground when the predicted demand on a destination airport exceeds its capacity, and system-wide delays often occur as a result.

However, while passengers understand delays due to bad weather, decisions about capacity in good weather are much more problematic. Current DOT methods of encouraging airlines to spread peak hour demand to avoid delays at busy airports consist basically of jawboning and persuasion. Failure of these techniques means massive inconvenience and public uproar. Yet devising and implementing equitable methods of managing demand pose difficult and sensitive policy questions for the government. Air and ground space management may require imposing surcharges or altering airline schedules and airport landing slots at the most congested facilities during peak hours—actions that directly affect airline profits and market share. **OTA finds that technical expertise from FAA is essential to DOT and Congress in making difficult decisions on constrained airport and airspace capacity. Continued emphasis on developing analytic tools, including models, to help understand the capacity of the air traffic system would provide FAA with vital technical knowledge to support difficult future decisions on capacity, safety, noise, and airline scheduling.**

Air traffic equipment improvements, flight path restructuring, and well-trained operating and support personnel are important near-term safety improvements given existing and projected airport capacity constraints. Both realistic scheduling and a fully staffed and adequately equipped ATC system are required for the system to be able to handle safely continued growth in air travel without burdensome delays. FAA considers the new Host computers in en route centers to be adequate until the Advanced Automation System is available. However, these computers address only some of the current system problems. For example, computer and radar capabilities in the Terminal Radar Approach Control (TRACON) facilities are inadequate to handle the increased traffic load that will occur when broadened requirements for altitude encoding transponders in GA aircraft are implemented. (For further information, see chapter 7.) Currently, the New York TRACON equipment is being upgraded to handle increased demand. However, in late March 1988, FAA announced a request for fiscal year 1989 funds to upgrade equipment at other TRACONs. **OTA finds that these equipment improvements should be completed as quickly as possible. They are essential to the successful implementation of broadened transponder and collision avoidance equipment requirements. Congressional support for funding will allow an important addition to system safety to go forward.**

Personnel and Training

FAA and DOT budget decisions in the early 1980s to reduce personnel levels created shortages of trained personnel in three critical areas (see table 1-4), and the safety system continues to feel the effects. For example, the ranks of trained operations and maintenance inspectors have become very thin, while airline operations have been changing rapidly and dramatically. Federal processes are so slow that FAA became adequately staffed to handle new industry entrants only in 1984, the year that new airlines began to go bankrupt or merge with established carriers. **OTA concludes that FAA inspector, controller, and technician work force levels still do not meet system safety requirements.**

DOT's budget request for fiscal year 1989 includes funds for about 2,500 inspectors. However, hiring

Table 1-4.—Selected FAA Employee Totals, 1978-87

Occupation	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Air traffic controller[a]	16,750	16,853	16,584	6,658	11,416	11,946	11,944	12,245	12,429	12,847
Aviation safety inspector[b]	1,466	N/A	1,499	1,615	1,423	1,331	1,394	1,475	1,813	1,939
Electronics technician[c]	9,423	9,209	8,871	8,432	8,031	7,633	7,229	6,856	6,600	6,740

[a] Full performance level and developmental controllers at towers and centers.

[b] Air carrier inspectors (approximately 40 percent of the total) were responsible for 145 air carriers, while general aviation inspectors were responsible for 173 Part 135 commuter airlines, 7,804 other commercial aircraft operators, and 5,210 aviation schools and repair stations as of Mar. 10, 1988.

[c] Communications, navigational aid, radar, and automation technicians.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration data as follows: controller data as of September 1987; inspector data as of March 1988; and technician data as of March 1988.

an adequate number of inspectors is just the beginning. As aircraft technologies become more complex and sophisticated, training for aviation inspectors will become even more critical. While efforts at FAA headquarters to standardize inspection procedures and job descriptions are underway, they will not be completed for at least another year. FAA inspectors continue to operate according to the policies and on-the-job training of the particular field office in which they are located, leading to substantial inequities in enforcement. **OTA concludes that immediate steps to speed standardization of inspection procedures and provide adequate recordkeeping for agency inspection information are priority needs.** Project SAFE, FAA's program to accomplish these goals, is a move in the right direction, but progress is painfully slow.

Moreover, FAA headquarters, Aviation Standards field offices, and the FAA Academy need a coordinated long-term plan for number of students, curriculum, and training equipment. Frequently, Academy courses do not adequately prepare inspectors to take up their duties once they return to the regional offices. Regional offices, desperate to have adequately trained personnel to meet the needs of the airlines they supervise, provide independent training that varies from region to region, perpetuating the regional differences in application of supposedly national standards. At present, the Academy must react to unforeseeable short-term needs, rather than proceeding efficiently to improve its training capabilities.

The firing of striking air traffic controllers in 1981 is an example of a Federal decision made for national labor policy reasons but felt keenly by FAA. Hiring of new controllers lagged far behind the need, and a few aftereffects linger to this day. While some facilities have a plethora of new controllers, they cannot give them training and experience quickly and efficiently to relieve the full-performance level controllers or replace those who retire. Still other facilities, such as those in the New York City area, cannot attract new controllers because of the high cost of living. Federal policies do not permit cost of living differentials to be paid for employees assigned to high cost areas of the country.

Furthermore, air traffic controller training programs and equipment are outdated and badly in need of carefully planned and systematic overhaul. Air traffic controllers at some en route facilities now receive site-specific training at the FAA Academy in Oklahoma City because of inadequate resources at the en route facilities. **OTA finds that improved simulation training for air traffic controllers is potentially more cost-effective than present programs.**

As NAS becomes more fully automated, personnel who maintain NAS equipment will require more sophisticated training. Moreover, planning realistically for maintenance personnel needs early in the technology development process is important. Past reductions in facilities technician ranks have made maintaining aging ATC equipment difficult. Conditions at the FAA Academy are not conducive to attracting first-rate instructors to train a new generation of airway facilities maintenance personnel, and maintenance training is an afterthought in the technology development process.

OTA concludes that support and funding from FAA headquarters for immediate and long-term programs to upgrade inspector, controller, and technician training are vital to ensure a trained work force capable of handling future system safety needs. Congress may wish to consider legislation to permit hiring of retired personnel to maintain sufficient levels of expertise. Furthermore, Congress may wish to encourage FAA to raise the grade levels of instructors at the Academy and institute policies to allow easier movement between the field and the Academy.

Technological advances and changes in the aviation industry bring new aircraft technologies that are beyond FAA expertise for ensuring adequate safety standards. Furthermore, aircraft maintenance procedures have changed substantially, and FAA does not have adequate numbers of expert technical personnel or training capabilities for new staff, nor does it have funding available to attract them from industry. FAA programs such as Project SMART[7] and National Resource Specialists are steps to address this issue, but FAA must rely on competence and professionalism in the manufacturing and operating industries to ensure airworthiness of commercial aircraft. The future will continue to bring new and increasingly sophisticated commercial aviation technologies, many of which will be introduced not for the sake of safety, but for the economic benefits they promise. Nonetheless, if introduced in the proper way, many hold the potential for decreasing the risk of an accident. **OTA finds that, in the long term, FAA will need greater expertise on its staff in areas of new aviation technology to provide oversight comparable to today's. Congress may wish to consider making funding available specifically to bolster FAA's expert technical staff.**

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[7] Project SMART is a plan to upgrade the Federal Aviation Administration's aircraft certification regulatory program.

TECHNOLOGIES TO ENHANCE SAFETY

Historically, technological advances have contributed greatly to increasing safety. While further safety advancements through technology will be relatively costly, OTA concluded that several technology areas show real promise for improving safety, even as demands increase on the air system.

Severe weather is a contributing factor in many aircraft accidents, and the most common types of fatal weather accidents involve either windshear near the ground or icing prior to takeoff. Sensors such as Terminal Doppler Weather Radar (TDWR) hold potential for rapid detection of dangerous windshear. However, TDWR's great expense suggests that other, less expensive technologies could be examined for use at smaller airports to augment the enhanced Low Level Windshear Alert System. **In addition, OTA concludes that training programs for pilots in recognizing and coping with severe weather, such as windshear, could be required for all commercial pilots. An R&D program in cooperation with industry to improve icing detection and de-icing of aircraft before takeoff and an improved cockpit crew training program for winter flying are other priorities.**

Furthermore, current air/ground communications are not adequate in some cases to support pilot needs for both real-time ATC and real-time weather information. Providing ATC information to ensure separation between aircraft in the air and alert aircraft flying too low to the ground is the controllers' first priority. At times controllers are too busy to transmit weather information to pilots or are distracted from transmitting information by more urgent demands to separate traffic. Pilots need better weather information in the cockpit, and programs to develop message formats and workable air/ground communications for weather information are important immediate safety needs. **OTA finds that rapid development and operational testing of alternative approaches to air/ground communication of weather information in parallel with weather sensor development would improve safety.** For the longer term, digital air/ground data links with an appropriate level of automation can remove controllers from the process of relaying weather information to pilots, thus reducing controller workload. However, the human factors issues related to automated, digital communications for both controllers and pilots are not well understood. **OTA concludes that R&D efforts on data link services, human factors, and system integration have a potentially high payoff for efficiency as well as safety.**

Midair collisions account for about 5 percent of all fatal accidents involving airlines and about 10 percent of fatalities. The Traffic Alert/Collision Avoidance System (TCAS), the technology chosen by FAA for backing up the ATC system in collision avoidance, will help to eliminate these accidents. TCAS warns pilots only of nearby aircraft with operating transponders. Recent legislation requiring transponders for aircraft operating in terminal airspace where radar service is provided will enhance TCAS effectiveness in preventing collisions. TCAS has taken years to reach readiness for operational testing, due to the time required for technology development, testing, and certification. Because TCAS-II, required for commercial airlines in recent legislation, advises the pilot of vertical maneuvers only, efforts are underway to prepare TCAS-III, which suggests both horizontal and vertical maneuvers. Yet unknown are human factors and ATC issues that may be associated with widespread use of TCAS, although none of these issues appears to be a crucial stumbling block to TCAS implementation.

Although the United States has had few fatalities from collisions on the airport surface, a number of nonfatal collisions and close calls have occurred. As air traffic levels climb, the probability of a disastrous ground collision may increase unless compensatory steps are taken. **OTA finds that ground safety could be improved by more uniform sign symbols on the airport surface, control lights at entrances to active runways, and procedural and training programs for pilots and controllers on ground safety. Surface detection radar upgrades, such as FAA's planned ASDE-3 radar, which presents ground traffic information to controllers, are important safeguards against ground collisions at larger airports.** These radars can be enhanced to provide conflict alert to controllers and can eventually be integrated with digital air/ground communications to provide alerts directly to pilots. Congress may also wish to require exploration of low-cost programs such as signs and lights. Eventually, advanced display and communications systems and new types of sensors may also improve ground safety.

For the long term, although a program is underway to automate ATC through the Advanced Automation System, serious questions remain regarding the degree to which the goals of this program will be met, as well as about the human factors aspects of automation. **Further examination of the potential hazards and efficiency gains resulting from automation of controller functions could clarify whether the Advanced Automation System will meet its goal of safe control of higher traffic levels. OTA concludes that such research is a priority for FAA attention.**

R&D Management

Schedule slippages and cost overruns in NAS Plan programs are not unusual for a government program of its size and technological complexity. **However, FAA's management of technology development for the NAS Plan could be improved.** More attention could be focused on rapid development of safety-critical NAS upgrades in areas such as air/ground communications and ATC facilities. For the longer term, more emphasis is needed on life-cycle planning to include adequate time for system development and testing to meet the ultimate goal of the NAS Plan: to provide the means for NAS users—pilots and passengers—to fly safely and efficiently. Internal FAA coordination and management incentives need to be clearly tied to this goal.

Recognizing that important near-term needs exist, FAA has established an interim support program for NAS. However, FAA has done relatively little near-term or longer-term research to support NAS developments. The new operations research and analysis effort known as the NAS Performance Analysis Capability deserves continued support. Such efforts can help FAA identify emerging ATC problems and parameters for solutions to the problems. Prototyping and test bed technologies to help evaluate technological and operational alternatives are important to investigate more fully ways that encourage innovation and timely fielding of technology.

FAA SAFETY DATA PROGRAMS

Commercial aviation accidents are such rare events that statistically valid trends often require at least 5 or more years of data. Accident data thus have limited value over short periods of time or for forecasting trends, and OTA concludes that the immediate effects of policy decisions cannot be monitored by short-term accident data. For example, the consequences of recent requirements for collision avoidance and transponder equipment will not appear in the accident data for many years.

Nonaccident data, however, can be used for short-term safety analyses, and FAA programs collect or have available to them a great deal of data for monitoring and assessing safety. However, while three separate FAA divisions have safety data responsibilities, databases, data terminology, and automated systems are often incompatible. Additionally, the agency uses most of its databases for recordkeeping and not for analysis and does not adequately emphasize accuracy or consistency, OTA concludes.

The few FAA studies that use nonaccident data appropriately have come from the Office of Aviation Safety, and for the most part address such FAA concerns as near midair collisions and air traffic controller errors. Four data areas—aircraft mechanical reliability, airline operating practices, inspection results, and the financial condition of airlines—contain helpful information for analysis. However, the effects on safety of airline practices, or changes in them, are rarely addressed in FAA studies, although FAA principal inspectors have a good understanding of their respective air carriers' safety approaches. A program to consolidate and communicate the knowledge through consistent, centralized records on the number, extent, or results of air carrier inspections could enhance safety. **OTA finds that automating inspector recordkeeping and allocating resources to ensure that the system, including training, meets the needs of the field offices are important priorities for the Office of Aviation Standards.**

Airlines themselves keep vital safety information, and FAA could benefit from working more closely with airline data, although ensuring the confidentiality of the air carrier data is crucial. **FAA could encourage improved air carrier reporting of sensitive safety data, such as incidents, by guaranteeing that no penalties will result from reported information and by making *nonreporting* a violation.** Additionally, access to airline computer systems, such as maintenance management systems, could enhance FAA's monitoring capabilities. One major airline already provides FAA with on-line access to its computerized maintenance database.

OTA finds that across FAA the management structure for data responsibility needs review, and that coordination of efforts by the Offices of Aviation Standards, Air Traffic, and Aviation Safety could promote a system safety approach. The data systems themselves could be significantly improved and coordinated with active participation by data managers, analysts, and field personnel in all three sections. **OTA concluded that system safety would benefit if the Office of Aviation Safety played a coordinating and supporting role to Air Traffic and Aviation Standards efforts, rather than continuing its present emphasis on investigation and oversight.**

Incorporating human factors needs into planning and procurement is an important component of system safety management. Historically, aviation accidents have declined after major technology advances, prompting reliance on technological solutions for safety problems. However, regulations governing training programs for cockpit crews are 20 years old and do not include changes appropriate to some advanced technologies. At present, numerous and substantial changes to airline training programs are covered by exemptions to Federal Aviation Regulations, granted on a case-by-case basis with little analytical support. **OTA finds that FAA's regulatory program has not identified or addressed many training issues that are crucial to ensuring safety. Congress may wish to direct FAA to allocate resources and management personnel to develop guidelines and advisories for revising training standards and cockpit certification methods. Close coordination with ATC and controllers is imperative.** Key areas for federally supported research or regulatory efforts include operational data collection, physiological and psychological factors, crew management, and optimal use of automation in the cockpit and in ATC facilities.

Chapter 2

Airline Economic Context

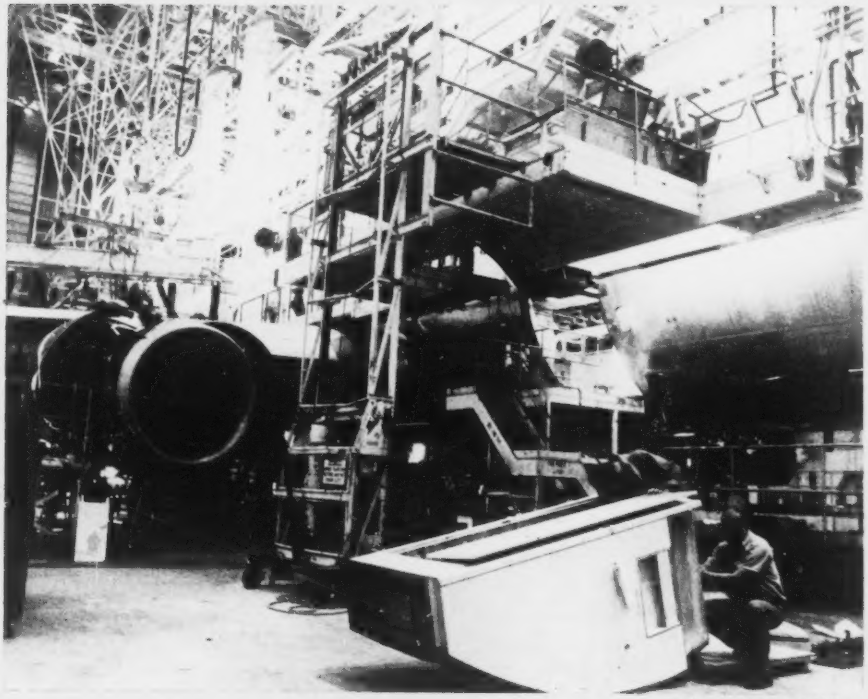

Photo credit: United Airlines

Discretionary maintenance is an economic decision.

CONTENTS

Page
Commercial Air Transportation—Major Changes 25
  Growth in the Industry 26
  Consolidations 27
  Aircraft Acquisition 29
  Regional Airlines 29
  Shift Away From Open Entry 31
  International Ties 32
Operational Changes 32
  Hub and Spoke Service 33
  Code-sharing 33
  Computerized Reservation Systems (CRS) 33
  Controlling Costs 34
Profit and Debt Trends 35
Policy Issues Related to Industry Changes 36
  Airport Capacity 36
  Demand Management 38
  Effects of Consolidations on Employees 39
  Federal Labor Policy Changes 39
Public Policies Affecting Airline Operations 40
  Air Traffic Controller Strike in 1981 40
  Federal Budget Cutbacks and FAA Inspection Program 40
  Environmental Concerns 41
Conclusions 41

Box

Box *Page*
2-A. Airport Scheduling Meetings 37

Figures

Figure *Page*
2-1. Scheduled Airline Passengers 27
2-2. Air Traffic Activity at Selected Hubs 28
2-3. Large Aircraft in Commercial Service 29
2-4. Industry Market Share: Revenue Passenger-Miles 30
2-5. Expense Indicators of Major Airlines, 1978-1986: Labor and Maintenance 34
2-6. Net Profits of Major Airlines, 1986 36

Tables

Table *Page*
2-1. Commercial Aviation Traffic Statistics, 1986 16
2-2. Regional Airline Revenue Passenger-Miles 30
2-3. Percentage of Passengers Enplaned by Airlines at Selected U.S. Airports 32

Chapter 2

Airline Economic Context

Over the last 10 years, many aspects of the commercial aviation industry have changed profoundly as carriers seized opportunities offered by economic deregulation. Airlines that once changed routes and fares infrequently now serve a wide array of markets, offering competitive fares and frequent flier awards to attract passengers. While the public enjoys lower fares and expanded service in some markets, concerns about airline safety focus on how airline managements balance maintaining safety procedures and controlling operating costs.

Prior to passage of the Airline Deregulation Act in 1978, the Civil Aeronautics Board (CAB) supervised the economic life of the industry, controlling entry of new airlines, establishing routes carriers could fly, and setting fares. CAB made such decisions after hearings and negotiations that often took months and even years to complete. During the hearing process, CAB members considered the economic effects of any requested change on the carrier, competitors in that market, airport operations, and the interests of the public. This comprehensive economic management ended when Congress dismantled CAB with the expectation that the public would benefit from a less regulated industry—one easier to enter and more responsive to price competition.

Understanding the current economic and institutional context of this complex industry, now disciplined primarily by market forces, is important background for evaluating safety issues and the Federal role. Thus, this chapter reviews the airline industry's growth and major structural and operational changes that have occurred since deregulation, explores public policies that affect the airline industry and safety issues, and concludes with the economic outlook for the industry.

COMMERCIAL AIR TRANSPORTATION—MAJOR CHANGES

Commercial air transportation includes flights by scheduled large jetliners, smaller commuter planes, and air taxis, as well as cargo and charter jet service. Each industry segment has substantially different safety and economic effects on the aviation system. Although subdivided differently by the Federal Aviation Administration (FAA) and the Department of Transportation (DOT), the two broad categories of airlines of concern to this report are:

- 14 CFR Part 121—operations of aircraft with more than 30 seats or 7,500 payload-pounds;
- 14 CFR Part 135—operations of aircraft with 30 seats or fewer.[1]

Part 121 is usually associated with the major carriers and Part 135 with the commuter airlines.

OTA estimates that 450 million passengers traveled on all commercial flights in 1986, as shown in table 2-1. Large airlines operating under Part 121 carried 95 percent of the passengers and accounted for 99 percent of the revenue passenger-miles. Part 135 commuter airlines transported 4 percent of the passengers and air taxis only 1 percent. Figure 2-1 shows the trends in passenger levels for the scheduled industry segments for each year since 1975.

While passenger statistics are one good way to measure commercial aviation, other data are needed to assess its effects on the air traffic control (ATC) system. For example, commuter airlines and air taxis have a much greater impact on airports and air traffic than passenger data indicate, because small propeller-driven aircraft take up nearly as much air and runway space as wide-body jets. Therefore, data on aircraft departures are needed to ascertain the relative impact of each industry category on the national airspace system. Commercial air transportation operations (takeoffs and landings) at U.S. airports with FAA control towers have reached record levels each year since 1984, with commuters and air taxis accounting for one-third of those flights.[2] Because

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[1] These definitions can be confusing; 14 CFR 241 and 14 CFR 298 (and the general public) apply the terms "commuter" or "regional" to scheduled operations of aircraft with 60 seats or fewer.

[2] Air traffic controllers, who record data on traffic operations, do not differentiate commuters from air taxis or Part 121 commuters from

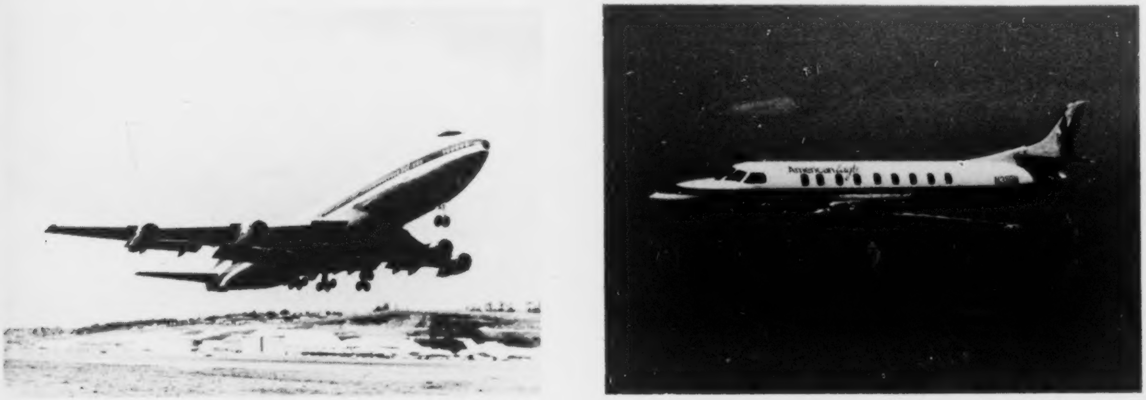


Photo credit: Boeing Commercial Airplane Co.

Photo credit: Fairchild Aircraft Corp.

Carriers operating large jets (left) are governed by 14 CFR 121, while commuter airlines flying smaller aircraft often follow 14 CFR 135.

Table 2-1.—Commercial Aviation Traffic Statistics, 1986

Industry category	Passengers enplaned (millions)	Revenue passenger-miles (billions)	Aircraft departures (millions)	Aircraft flight hours (millions)
Part 121				
Scheduled 121	418.5	366.3	6.4	9.4
Nonscheduled 121	7.3	12.3	0.2	0.4
Part 135				
Scheduled 135 (commuters)	18.3[a]	2.5[a]	2.4	2.3[a]
Nonscheduled 135 (air taxis)	6.5[b]	1.0[b]	2.5[b]	2.9
Total	450.6	382.1	11.5	15.0

[a] OTA estimate based on Regional Airline Association data.

[b] OTA estimate based on National Air Transportation Association and other air taxi data.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration and National Transportation Safety Board published data unless otherwise noted, as of January 1988.

general aviation (GA) activity has declined substantially, total traffic nationwide is still below the peak of 69 million operations reached in 1979. Although GA and military flights generate a large volume of traffic nationwide, they represent only a small portion of the operations at the largest and busiest airports—less than 6 percent at Chicago O'Hare and Atlanta Hartsfield, for example. The traffic growth at four post-deregulation hubs, shown in figure 2-2, illustrates how commercial airline traffic has increased rapidly and now dominates these airports, while GA has held steady or declined. (The small declines in 1987 airline traffic at Detroit and St. Louis are results of airline mergers, rather than travel reductions.)

Since most commercial aircraft operate under instrument flight rules, en route radar operations have reached new peaks each year since 1984. Currently, commercial transport operations account for over 60 percent of the workload for en route traffic controllers. For further discussion of air traffic issues see chapters 5 and 7.

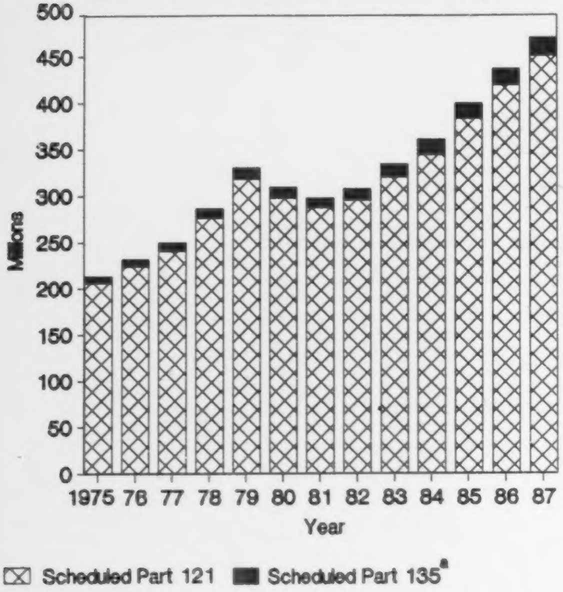
Growth in the Industry

The commercial airline industry has grown at an unprecedented rate since deregulation. Although growth has been sporadic, between 1979 and 1986

(continued from previous page)

Part 135 commuters. Additionally, since many air taxis are similar to general aviation aircraft, an air taxi operation probably will not be counted as such unless it is so indicated in the flight plan. Therefore, air taxi operations are most likely underestimated by these statistics.

Figure 2-1.—Scheduled Airline Passengers



[a]Part 135 passenger counts estimated by the Office of Technology Assessment.

NOTE: Nonscheduled 121 and 135 carriers increase the total by about 3 percent for recent years.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration and National Transportation Safety Board data.

air travel measured by revenue passenger-miles on scheduled Part 121 flights expanded from 226.8 billion to 366.3 billion, a total of 62 percent. During the last decade, takeoffs and landings of commercial airlines including both Parts 121 and 135 flights have increased from 13 million to 19 million annually. Although the industry has recently consolidated dramatically, 119 new air carriers entered the market between 1978 and the end of 1986. Also, the number of commercial aircraft has increased substantially during the 1980s. As shown in figure 2-3, commercial carriers added 1,007 large jets to their fleets between 1980 and 1987 for a 42 percent increase and are expected to have a total of 3,528 in 1988. New orders indicate fleets will continue to expand in the next couple of years.

The country's economic boom between 1983 and 1987 was partially responsible for these robust growth figures; however, the absence of economic restraints also encouraged airlines to expand services and to become more competitive. Moreover, these factors set the stage for structural and operational changes in the airline industry.

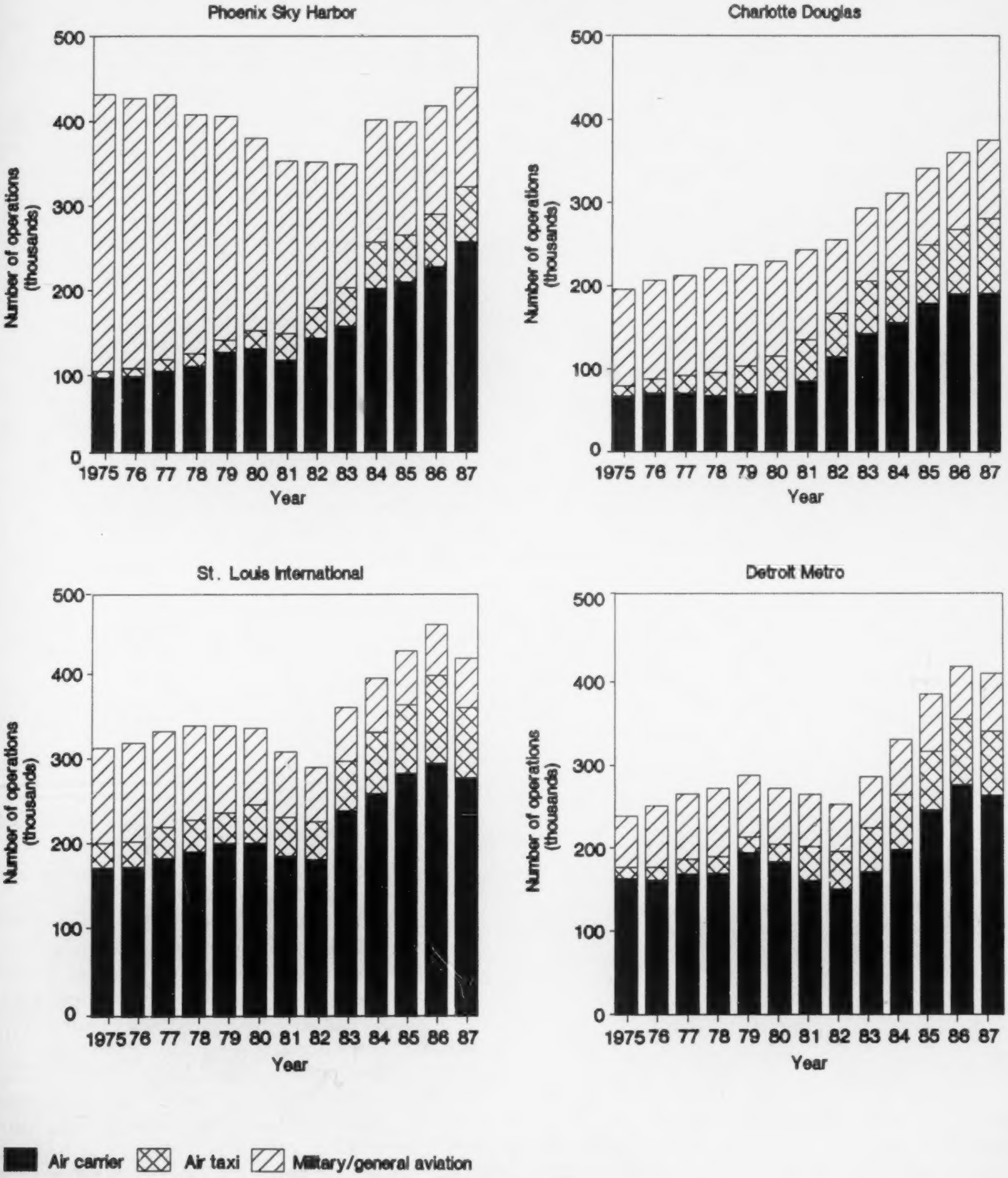
Consolidations

By 1987, the independent carrier, once the industry's principal structural unit, had almost disappeared, replaced by large financial organizations that control several airlines and/or affiliates and have broad ties to the national financial network. Nonetheless, ownership changes, reorganizations, failures, or threats of takeovers among U.S. airlines still occur occasionally. On the other hand, some industry characteristics have come full circle since deregulation, and many factors now exist that make it almost as difficult to enter the business today as it was prior to 1978, except in specialized market niches.

Despite the large numbers of new carriers entering business in the early 1980s, rapid consolidation has occurred in the aviation industry during the last 3 years. The recent mergers and takeovers apparently conclude the decade-long debate about how deregulation would affect the structure of the industry and support those who forecast a consolidated industry with many trappings of an oligopoly. (Oligopoly is an economic term meaning there are only a few producers of a product, and little or no differentiation exists among products or price.)

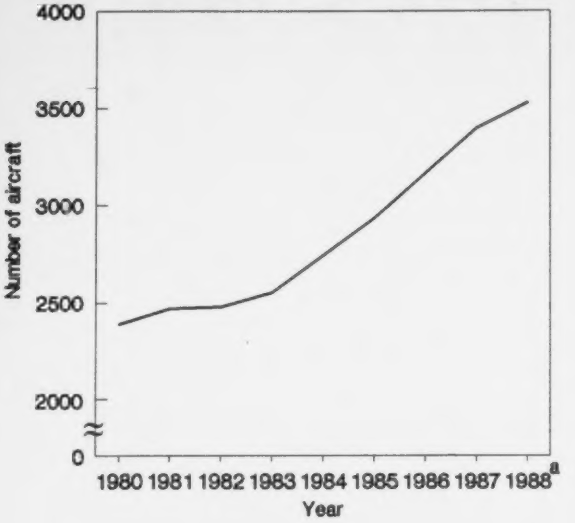
All the larger passenger air carriers that existed in 1985 have been involved in some sort of a consolidation; three mergers involving major and national carriers occurred in 1985, eight in 1986, and one in 1987. The recent slowdown in the frantic activity of the last 3 years is a result primarily of the small number of remaining merger candidates. Fewer firms control more of the industry's traffic now than in 1978, when the industry's eight largest firms enjoyed 81.5 percent of industry's traffic. By 1984, the percentage of passengers carried by the eight largest firms had dropped to 76.3 percent, and many industry analysts were convinced that the major airlines were losing some of their market power and that new carriers would play a growing role. However, by 1986, the industry had concentrated as a result of mergers and acquisitions, and the top eight carriers controlled 88.4 percent of the market (see figure 2-4). By the end of 1987, the eight largest airlines had increased their market share to over 92

Figure 2-2.—Air Traffic Activity at Selected Hubs



SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

Figure 2-3.—Large Aircraft in Commercial Service



[a]Forecast.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration forecasts, fiscal years 1986-1997.

percent, not including the traffic carried by regional affiliates.

To reach this degree of concentration, airlines reorganized through mergers or acquisitions. In the case of Texas Air, the holding company acquired two airlines—Eastern and Continental—which it operates as semi-independent units under its corporate umbrella. One of these units, Continental, has absorbed Frontier, People Express, and New York Air through mergers and acquisition. AMR, the American Airlines parent organization, owns the airline and several smaller carriers, and also operates Sabre, a computerized reservation system, as a separate subsidiary. Holding companies do not always manage similar or related companies, frequently selecting their subsidiaries as much for profitability as compatability. The significance of the holding company structure lies in the dual responsibility the airline management has for its operations as well as to the economic goals of the parent organization.

Aircraft Acquisition

Two trends in aircraft acquisition signal major operating changes for the industry. First, changes in the tax laws have made leasing equipment a more attractive option for airlines.[3] Firms such as Delta and Northwest, which have in the past owned most of their own aircraft, now lease some of their fleets. If growth in leasing activity continues, a large part of the domestic fleet could be the property of leasing companies and aircraft manufacturers. This more flexible arrangement reduces the carriers' long-term capital commitments and limits financial risk, an advantage if the industry experiences an economic downturn and finds itself with excess planes. Leasing equipment also changes the way some airlines manage maintenance (for further information, see chapter 5).

Second, competition for sales among the world's three major commercial transport manufacturers, Boeing, McDonnell Douglas, and Airbus, is fierce, and as a result they are willing to make favorable deals for carriers. American has negotiated an order split between Boeing and Airbus in which the manufacturers are leasing the equipment with generous renewal and cancellation provisions. Northwest has placed a major order with Airbus with the right to cancel any part of it on an annual basis without penalty. Also, manufacturers are including additional training and equipment maintenance service traditionally performed by carriers as part of lease or purchase deals. The long-term effects on safety of the manufacturers' willingness to offer service, training, and creative financing to make sales are not entirely clear, but in the short run it ensures new orders and an increase in available aircraft to the major carriers.

Regional Airlines

Spurred by deregulation, many small regional airlines entered the market in the early 1980s. Simultaneously, major airlines sought to extend their high density markets by increasingly dominating their hubs and sloughing off less profitable routes. Their actions encouraged regional airlines to provide service linking small cities and providing connections to hub airports. Because regional carriers use smaller aircraft and require less ground-based infrastructure, they can often operate such routes more profitably than the majors and provide a needed service.

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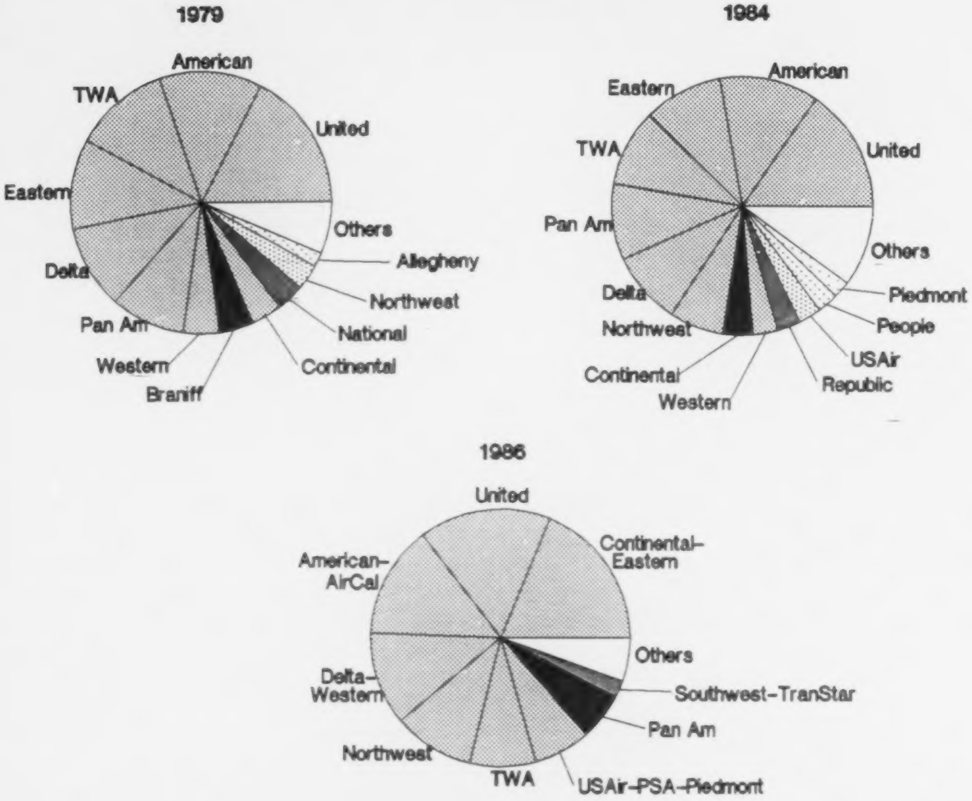
[3] Joan M. Feldman, "Airlines Learn To Cope With Tax Reform," *Air Transport World*, May 1987, p. 42.

Figure 2-4.—Industry Market Share: Revenue Passenger-Miles



SOURCE: 1979: Market share based on revenue passenger-miles (RPMs) of U.S. airlines performing scheduled service (226.8 million) as reported in Air Transport Association, "Air Transport 1979," June 1, 1979, pp. 20-21; 1984: Market share based on RPMs of U.S. airlines (296.3) million as reported in *Aviation Daily*, "Industry Market Share," Feb. 5, 1986, p. 200 (reverse); 1986: Market share based on RPMs of U.S. airlines (360.7 million) as reported in *Aviation Daily*, "Industry Market Share," Jan. 30, 1987, p. 150 (reverse).

As illustrated in table 2-2, the major increase in revenue passenger-miles for regional carriers occurred between 1978 and 1984; growth since 1984 has been relatively flat, increasing only 1 percent between 1985 and 1986. Also the number of regional carriers has dropped from a high of 250 in 1981 to the current level of approximately 150.[4]

Table 2-2.—Regional Airline Revenue Passenger-Miles

Year	Revenue passenger-miles (in billions)
1978	1.36
1979	1.72
1980	1.92
1981	2.09
1982	2.61
1983	3.24
1984	4.17
1985	4.41
1986	4.47

SOURCE: Office of Technology Assessment based on 1987 Regional Airline Association data.

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[4] U.S. Department of Transportation, Federal Aviation Administration, Planning Analysis Division, *FAA Aviation Forecasts, Fiscal Years 1987-1998* (Washington, DC: U.S. Government Printing Office, 1987), p. 50.

The recent low growth in traffic and the attrition among regionals can be explained in part by the absorption by the majors of regional carriers through acquisition or affiliations. Although some regionals, such as Ransome, have been acquired by major carriers, the more pervasive trend has been for the regional to establish an affiliation with a major carrier and feed traffic to its hub airports. As an affiliate, the regional is dependent on the major for marketing—usually sharing the major's code on published airline schedules and in computer reservation systems. The dependency is accentuated if the major also provides an affiliate with aircraft maintenance, fuel, and other essential services. Some majors try to raise the safety standards of regional affiliates by requiring an upgrading of operational standards as well as training and maintenance policies and procedures. While such arrangements are highly desirable for the major, enabling it to extend its market without appreciable capital expenditure, many regionals are dependent on their major carrier and fail if they lose their affiliation. Moreover, some localities have complained that regional airlines are more interested in satisfying the major carrier than in providing for community needs.

Lack of airport access is another factor contributing to the recent decline of regional carriers. Congestion at their hub airports has prevented some regionals from maintaining the on-time schedules needed to retain customers.[5] Furthermore, plans are in the works at some busy airports to reduce the number of regional flights served, as part of efforts to use runway capacity more efficiently.

As regional carriers find competition increasing for access to hub airports, the safety standards of local airports that serve small (Part 135) aircraft are being questioned. Currently, airports receiving their only scheduled service from Part 135 carriers are not eligible for certification under the FAA Certification Program. Certification requires airports to meet minimum standards for equipment and operations and to develop procedures to minimize loss of life and property in the event of an accident. A recent General Accounting Office study recommends that certification be required for all airports that receive regularly scheduled service, regardless of the aircraft size.[6]

Shift Away From Open Entry

A major argument in favor of deregulation was that CAB oversight had discouraged the entry of new firms into the industry and had created a government-regulated oligopoly. Yet of the 119 carriers that entered the industry between 1978 and 1986, only 35 were still operating at the end of 1986.[7]

The demise in 1986 of People Express, the model for carriers formed in the early 1980s, signaled the end of open entry in practical terms. Like some other new entrants, People Express had counted on an expanding market to finance the major maintenance needed after 2 to 3 years of operation. Head to head competition from established carriers in cities like Buffalo prevented buildup of capital, and for this and a host of other reasons, People's management was forced to seek a buyer to avoid bankruptcy. So many individual and institutional investors lost money on People and other new entries, and so few of the young firms still operating have provided attractive returns on investments, that Wall Street capital markets for new entrants are now essentially closed.[8]

Furthermore, would-be entrants now find many principal airline markets effectively closed. Existing hub operations cover most logical transfer points that also produce significant local traffic, and few opportunities remain to establish hubs at underutilized airports in major cities, as Midway did in Chicago. New entrants are further discouraged by the dominance of one or two carriers at hub airports as shown in table 2-3. The carriers that dominate in these hubs are fiercely protective and will-

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[5] OTA confidential airline survey.

[6] U.S. Congress, General Accounting Office, *Aviation Safety—Commuter Airports Should Participate in the Airport Certification Program*, GAO/RCED-88-41 (Washington, DC: U.S. Government Printing Office, November 1987), p. 9.

[7] Frank A. Spencer and Frank H. Cassell, Northwestern University Transportation Center, "Eight Years of U.S. Airline Deregulation: Management and Labor Adaptations; Re-emergence of Oligopoly," unpublished manuscript, January 1987, p. 37.

[8] Julius Maldutis, Solomon Brothers, unpublished manuscript of address at the Aero Club of Washington, DC, June 23, 1987.

Table 2-3.—Percentage of Passengers Enplaned by Airlines at Selected U.S. Airports

Airport	Air carrier(s)	Passenger percentage
Atlanta	Delta, Eastern	93.7
Charlotte	Piedmont	81.2
Chicago O'Hare	United, American	72.6
Dallas/Ft. Worth[a]	American, Delta	85.9
Denver[a]	United, Continental	86.9
Memphis[a]	Northwest	74.6
Minneapolis	Northwest	79.9
Pittsburgh	USAir	82.5
St. Louis	TWA	82.9

[a] Percentage includes totals attributed to merger and consolidation partners.

SOURCE: *Aviation Daily*, "U.S. Carrier Market Share at Leading U.S. Airports," June 3, 1987, p. 353 reverse-360 reverse.

ing to cut fares for as long as it takes to prevent a new carrier from establishing itself.

Furthermore, obtaining gate and terminal space is expensive, even where it is available; in many airports, the best gates and terminal counter spaces are leased on a long-term basis by major carriers. At capacity controlled airports, the cost of slots forms another deterrent—at Washington National and New York LaGuardia, slot costs are being quoted at $1 million each.[9]

Finally, aircraft procurement expense is a formidable hurdle facing a new carrier. Most of the new entrants during the early 1980s acquired their fleets when prices for new and used aircraft were depressed because of the recession. Today, used aircraft in good condition draw premium prices, and new jets cost well over $20 million.

International Ties

The U.S. airline industry is increasingly linked to the international market, and it is reasonable to expect that marketing and other financial ties between the United States and other countries will grow over the next few years.[10] Some U.S. airlines have found that low labor costs in some foreign air hubs make deploying some major maintenance abroad extremely cost-effective. At least two countries, Sweden and Canada, have proposed that cabotage restrictions between their nations and the United States be dropped. (Cabotage refers to the practice of preventing foreign carriers from flying U.S. passengers to more than one domestic destination on a single trip. For example, a Swiss flight from Zurich cannot fly to New York, pick up passengers and continue to Cleveland. It could, however, drop off New York passengers and then fly, half full of remaining passengers, to Cleveland, if it had bilateral permission to do so.) So far the United States has rejected these overtures, contending that the United States has more to lose than to gain by offering complete freedom of entry. However, future innovative marketing arrangements between carriers may modify arrangements between international carriers. Moreover, foreign airlines may participate directly in the U.S. industry through investment. Ansett Transportation Industries, Ltd., one of Australia's three major airlines, recently announced a plan to purchase 20 percent of American West Airlines stock—the largest percentage holding by any foreign airline in a U.S. domestic carrier. (Up to a 25 percent interest by foreign investors is allowed by U.S. law.) As part of the deal, Ansett will have one representative on the American West board, can establish links with its existing U.S. freight forwarding service, and will gain expertise in deregulation for when Australia deregulates its airlines.[11]

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[9] *Aviation Daily*, "American West Asks FAA To Reallocate Slots at National, LaGuardia," July 2, 1987, p. 10.

[10] *Aviation Daily*, "Analyst Predicts Worldwide Airline Integration," Mar. 18, 1987, p. 403.

[11] Michael A. Dornheim, "Ansett's Stock Purchase Will Place Foreign Stake in American West at 20 Percent," *Aviation Week and Space Technology*, July 20, 1987, p. 41.

OPERATIONAL CHANGES

Now that the marketplace determines profits, airlines have moved aggressively to expand market share and to hold down costs. The annual increases in air travel have been achieved by price competition, expanding service into new markets, and adjusting service to meet consumer demands. To control costs, managements have reduced staff and instituted a variety of tight cost management methods.

Hub and Spoke Service

Airlines have tried to maximize passenger seats filled by eliminating unprofitable routes and concentrating on lucrative high-density routes serving large- and medium-sized airports. The hub system establishes a number of routes connected to a central hub airport where passengers are collected from feeder flights, transferred to other flights on the same line, and are then carried to their ultimate destination. The traffic pattern at a hub airport consists of closely spaced banks of arrivals and departures. Passengers land at the airport and transfer to another flight within 40 to 50 minutes. Although Delta used Atlanta as a hub long before deregulation, most of the other majors adopted this pattern during the 1980s, because it permits service between more origin and destination points. Moreover, passengers can be retained by the airline for longer distances, raising the average revenue per passenger. In most cases, carriers choose a busy airport as a hub, so they can offer passengers a wide variety of possible connections as well as capitalize on already heavy origin and destination traffic. About three-quarters of the passengers at Atlanta and one-half at Chicago, Denver, and Dallas-Fort Worth arrive merely to change planes for other destinations.

While the shift of the major airlines from point-to-point service to hub and spoke has been a sound marketing tactic, it has forced adjustments in personnel and procedures that have substantial costs. Although hubbing allows carriers to centralize major maintenance facilities and inventory, aircraft often require servicing at a spoke where the carrier does not have repair capability. Contract arrangements may be made with another carrier for maintenance, or parts and repair crew may be flown in—at considerable expense.

Because hub and spoke operations rely on tightly scheduled arrivals and departures, congestion and delay can occur during peak hours, especially at airports such as Chicago and Atlanta, that serve as hubs for several major airlines. Moreover, the slots at these airports are one half-hour time periods. To maintain their position on computerized reservation systems, airlines tend to cluster arrivals and departures in the first 10 minutes of their slots, intensifying demands on an already full ATC system. Bad weather, requiring instrument flight rules, can make delays much worse. The additional costs attributable to congestion and delay such as fuel, missed connections, and customer dissatisfaction have caused some airlines to establish hubs at less busy airports, as Piedmont has done at Baltimore-Washington International. The largest carriers have established additional hubs at less busy airports, as American has at Raleigh-Durham.

Code-sharing

Code-sharing is a term that refers to two airlines, usually a major and a regional carrier, that share the same identification codes on airline schedules. By code-sharing with a regional airline, a major airline can advertise flights to a much larger market area and expand its market at relatively low cost. Prior to 1984, code-sharing existed only on the USAir-affiliated Allegheny Commuter service, but by the first half of 1987, the principal regional airlines were all code-sharing partners with a major airline. Code-sharing agreements vary widely and may include marketing and other tie-ins between the regional and major airlines, such as discount bulk fuel purchasing and terminal counter and gate sharing. Some of these agreements further lock in code-sharing affiliates by providing training, pooled aircraft purchasing, and other types of services that the regional could undertake only at much higher costs. While code-sharing arrangements can be mutually beneficial to both partners, the interdependence is often one-sided; the major is far less dependent on the smaller carrier than vice versa.

Computerized Reservation Systems (CRS)

CRSs are computerized systems that display airline schedules and prices for use by agents in making reservations. They are potent marketing tools, since approximately 90 percent of all reservations made by U.S. travel agents are made through these systems. Although five such systems are currently owned and operated by major airlines, American's

Photo credit: Karen Mathiasen, OTA staff

Travel agencies have access to flight schedules like these on their computer systems.

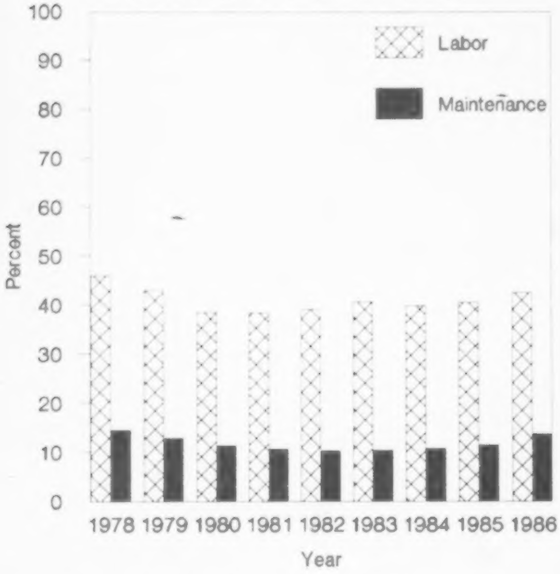
Sabre and United's Apollo account for 70 percent of the market use. CRSs have been expanded to make other types of reservations, such as hotel and rental cars. Fees from sales made using the systems are sources of substantial revenue and profits for their owners.

Since CRS is programmed to select flights based on published schedules, airlines find tremendous economic advantages in developing schedules that show flights to major cities arriving and departing during the early morning and evening peak hours. For example, to compete for lucrative business travel, airlines bunch arrival times at major airports at 8:30 or 9:30 a.m., in time for morning meetings. DOT's action to require airlines to report on-time performance was designed in part to prevent airlines from underestimating their actual flying time to gain a more favorable position on the CRS.

Controlling Costs

To maintain competitive fares and still make a profit, every airline has made intense efforts to reduce and control operating costs for labor, fuel, maintenance, commissions, and other services. Gone is the era when fares were controlled by CAB, and cost increases could be passed on to the consumer without the threat of losing business to another carrier.

Figure 2-5.—Expense Indicators of Major Airlines, 1978-1986: Labor and Maintenance



SOURCE: Office of Technology Assessment based on Congressional Research Service data.

Labor Costs.—Labor is the industry's largest operating expense, representing 42.6 percent of total expenses in 1986 (see figure 2-5), down from the 1978 peak of 46.1 percent. (The 1981 low in labor's share of total costs reflects increased fuel prices rather than significant reductions in labor costs.) Each airline devotes a different portion of costs to labor. In 1986, for example, Continental expended 22.8 percent of operating expenses for labor, while among the other majors, only Northwest at 28.4 percent spent less than 31 percent of total expenditures on labor.[12] Continental achieved its low labor cost partially as a result of its bankruptcy filing in 1983, which enabled it to nullify its existing union contracts. Setting an example soon followed by most major carriers, American initiated a two-tier pay structure in 1983 which paid new employees significantly less than existing employees. The strategy held labor costs down, but was very unpopular with employees, and has been significantly modified. After its merger with Republic in 1987, Northwest refused to raise pay levels for former Republic employees to equal those of Northwest personnel, creating a two-tier pay scale that was a persistent irritant. Other airlines undergoing financial difficulties have negotiated employee pay cuts, generally the most contentious issue in airline negotiations and acceptable to employees only when failure or bankruptcy seem likely alternatives. Finally, airlines have reduced or eliminated positions. Several have eliminated meteorology and safety sections, others now rely on manufacturers for engineering expertise that used to be a part of the airline's operations.

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[12] *Aviation Daily*, "Major and National Carriers Labor Expenses," July 15, 1987, p. 77 reverse.

Some airline holding companies have established nonunion subsidiaries that provide the same service at a lower cost than the carrier's union employees. This strategy, known as "double-breasting," was initiated by New York Air and is considered reprehensible by organized labor. Attempts to form subsidiaries through the transfer of existing union workers to new firms have met with fierce resistance from the affected unions. As the need has grown for skilled pilots and ground personnel, management has had to back off from severe wage and benefit inequities.

Maintenance Costs.—Industry data reported to DOT show that maintenance expenditures dropped from a high of 14.5 percent of operating expenses in 1978 to a low of 10.3 percent in 1982, a period of high fuel costs, and then rose to 13.7 percent in 1986. Airline maintenance spending, which includes refurbishing and remodeling aircraft as well as routine equipment maintenance, usually rises with industry profits that make available discretionary funds. In hard times, airlines undertake only the maintenance necessary to meet FAA standards. Since individual airlines allocate costs differently, conclusions about the safety impacts of maintenance expenditure fluctuations are very problematic. For further discussion see chapter 5.

Fuel Costs.—Fuel has been the most volatile cost for the industry, swinging between a high of 33.9 percent of operating costs in 1980 to a low of 19.6 percent in 1986. The industry has little control over fuel costs since it must generally pay prevailing prices.

Commissions.—Airlines have increased expenditures for travel agent commissions, and almost 11 percent of total 1986 operating expenses were commission payments, up from 5.5 percent in 1978. However, this shift occurred because airlines now rely on travel agents, aided by CRSs, to capture business. Indeed, CRS programs are so effective that many airlines have been able to reduce drastically their ticket sales forces.

PROFIT AND DEBT TRENDS

The last decade has contained both the industry's most profitable and least profitable years, not surprising given the extent of change within the airline industry. However, in a noteworthy departure from conditions during the regulated era, the profits and losses associated with these cycles have not been evenly distributed among the major carriers. Even in good years for the industry, certain firms have not fared well. In 1986, considered a profitable year for the industry overall, the vast majority of the net profits were concentrated in about half of the major firms (see figure 2-6). While all airlines have cut costs, some have been more successful than others in making money in a rapidly changing environment, and consistently, a few firms—American, Delta, Piedmont, USAir, and Northwest—have been more profitable than their competitors.

The leveling off and decline in interest rates has helped the industry reduce the impact of a large debt burden, which stood at $15 billion at the end of 1986.[13] However, the debt issue may be an industry time bomb. Some firms are earning enough to service large debt, while others are able to service their debt only by refinancing or taking other steps to reduce the burden. The debt load, like net and operating profits, is not evenly distributed among firms in the industry. For example, Texas Air carries the industry's largest debt, $4.7 billion, followed by AMR with $2.4 billion, TWA with $1.9 billion and Delta with $1 billion.[14] Although debt is not now a pressing problem, an economic slump could push marginally successful carriers into dangerous financial situations.

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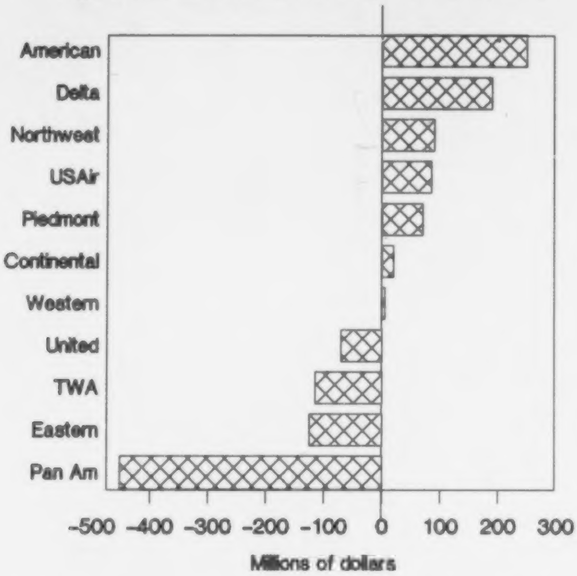
[13] *Aviation Daily*, "Intelligence," May 4, 1987, p. 185. Industry figure does not include Piedmont.

[14] Ibid.

Figure 2-6.—Net Profits of Major Airlines, 1986



SOURCE: Office of Technology Assessment based on Congressional Research Service data.

POLICY ISSUES RELATED TO INDUSTRY CHANGES

The numerous operating changes and economic considerations discussed in this chapter present difficult issues for public policymakers. Among the most compelling are the problems of allocating limited airport capacity in a safe, efficient, and equitable manner and the effect of mergers, reorganizations, and cutbacks on employee performance.

Airport Capacity

The majority of airports are small or regional facilities that have adequate capacity, and even at the busiest airports, demand exceeds capacity only at some times of day. However, because the demand exceeds the runway and gate capacity of the busiest hub airports at peak hours, congestion and delays frequently occur even in good weather, and are especially troublesome in bad weather. At those airports where capacity is an issue, every method of meeting demand has significant operational, economic, and safety implications.

During 1987, the number of delays reached record levels at certain airports and on some airlines, inconveniencing travelers throughout the system. Especially hard hit have been some commuter airlines that tend to lose customers under circumstances of hub congestion, since, except for early morning departures, they cannot maintain an on-time schedule.[15] The industry blamed the limitations of the ATC system, while FAA countered that while delay is often weather related, carriers' hub operations and CRS scheduling competition contributed to delay problems. (See box 2-A.) Passengers reacted with an all-time high in complaints. The causal relationship between congestion and airline safety is subtle and complex, and ground and airspace congestion place pressure on the ATC system, pilots, and aircraft equipment to operate with special regard for safety, even though delays may result.

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[15] OTA confidential airline survey.

Box 2-A.—Airport Scheduling Meetings

The Office of the Secretary of Transportation (OST) and airlines hold meetings when the number of delays due to overscheduling or other factors becomes unacceptably high. The high-density rule of 1968[1] limited operations at five heavily used airports, Kennedy, O'Hare, LaGuardia, Washington National, and Newark. Industry-government scheduling committees were formed at each of the airports to meet regularly and resolve problems. In the early 1980s, the scheduling process began to break down, with numerous resulting delays, and the Department of Transportation (DOT) issued a rule to allocate slots and permit their sale at Kennedy, LaGuardia, O'Hare, and Washington National.[2] Currently DOT now conducts scheduling meetings involving the Federal Aviation Administration (FAA), OST, and airline representatives when delays at these or other airports become a major problem, although such meetings are not held on a regular basis. The first meeting was held in November 1984 (the "Crystal City meetings") and the second in the spring of 1987 to address the peak hour problems at Newark, Philadelphia, Dallas-Fort Worth, O'Hare, and Atlanta. Another set of meetings was held in late 1987 to prepare for a 6-month runway closure due to a major repair at Los Angeles.

Three causes create schedule peaks: hubbing operations; customer demand—although this is hard to isolate, and demand peaks may spread over 2 hours; and, probably most important, the computer reservation system. Travel agents sell tickets according to the list of flights that appears on the computer screen. The listing gives priority to flights with times nearest the requested time. Customers tend to request flights on the hour, so most lists first show flights near the beginning of the hour. Flights farther away from the hour may not even appear on the first screen or even the third at the busiest airports. Customers select the first flight on the list more often than any other flight, and select flights on the first screen more often than flights on later screens. Therefore, flights scheduled near the beginning of an hour have a marketing advantage over other flights. Even the four airports with regulated slots are subject to the peaking problem, because slot durations are at least 30 minutes, and airlines with slots can and do bunch flights on the hour.

DOT relies on FAA technical expertise to judge airport capacity. Capacity is an extremely complex issue depending on weather, runway configurations, and noise restrictions. Airlines resent limits on scheduling and sometimes dispute FAA procedures and capacity estimates, maintaining that air traffic control procedures need to be improved, holding patterns better used, and separation standards reduced. They also would like to see more airports and runways constructed.

FAA conducts the meetings, and, despite these airline complaints, tries to view the situation from the air traffic control standpoint, warning the airlines that flow control will hold flights on the ground if overscheduling persists. OST is present at the meetings to guarantee anti-trust immunity by ensuring that no deals are cut between carriers, and to represent the consumer viewpoint on the importance of maintaining schedules and avoiding delays. In practice, OST has found it necessary to enforce its policy objectives through investigations and delay reporting rules. While investigations are still ongoing, in 1987 OST did achieve some of its objectives—airlines have signed agreements to adjust their schedules at four airports that chronically had late flights. Schedules at these four airports improved, although Atlanta remains a problem because a major airline with a hub there would not agree to many changes in its schedule.

A similar meeting was held in Los Angeles to determine how to cope with the impending closure of one runway for repair. After considerable deliberation, both major airline users agreed to reduce their schedules for Los Angeles during the period of major work. Although participation in the meetings and implementation of agreed upon changes are completely voluntary,[3] one anonymous observer has likened them to auctions where no one wants to bid.

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[1] 33 *Federal Register* 17896 (Dec. 3, 1968).

[2] 50 *Federal Register* 52180 (Dec. 20, 1985).

[3] Cynthia Burbank, U.S. Department of Transportation, Office of the Secretary, personal communication, Dec. 4, 1987.

FAA innovations, such as the reconfiguration of airways under the East Coast Plan, are proof that improved management can increase capacity in parts of the system. However, actions to alleviate one problem often create another. In the case of the East Coast Plan, changes to ease delays for traffic between New York and Washington adversely affected Philadelphia. Physical improvements in airport facilities, such as additional runways, may be a partial solution to the capacity problem, but difficult issues related to noise and land use control preclude substantial relief in the near future. Technology can increase the capacity of airports to a limited extent by allowing fuller, more efficient use of existing facilities; actions for improvements are discussed in chapter 7.

Demand Management

One approach to controlling congestion and delay is by managing demand; tactics include limiting access by restricting certain types of aircraft, pricing policies, and quotas or slot control. Prohibitions such as those based on size work best in situations where there is an alternative airport to which restricted carriers can be diverted. To forbid some portion of the traffic to use an airport without an available alternative is likely to be considered a restriction of interstate commerce or discriminatory practice.

Officials of the Massachusetts Port Authority (Massport) have recently proposed a plan for revising landing and terminal fees at Logan Airport that would raise use charges for small aircraft to more nearly equal those paid by large carriers and would eventually add a premium to charges for peak hour operations. The plan, to be implemented July 1, 1988, raises the base minimum landing fee from $25 to $88 and reduces the landed weight charge from $1.31 per 1,000 lb. to $.47.[16] In effect, the plan increases charges for aircraft with 30 seats and fewer while substantially reducing charges for large passenger jets. Massport estimates that while the pricing plan will reduce Logan operations by only 5 percent, it will cut delays up to 80 percent, because the reduction of small, slower GA or commuter flights can improve runway capacity. Similar aircraft can be more uniformly and efficiently spaced on approach and departure, thereby smoothing out irregularities in the traffic stream, a prime cause of delay.

Representatives for GA and regional airlines protested that the Massport plan is discriminatory, and Massport has exempted from the proposed fee changes regional airline flights from 14 New England communities that have "Essential Air Service" to Logan. The Regional Airline Association claims the plan will reduce or eliminate air service to most of the other 30 cities served by regional airlines operating in and out of Logan. Whether FAA has the authority to make a decision on the discriminatory nature of the plan under Federal laws and regulations is likely to be tested in the courts. Regardless of the outcome, the concept of restricting traffic through pricing is one many advocate. Port Authority of New York officials are considering a large increase in the minimum peak hours fees for the three airports they manage: Newark, Kennedy, and LaGuardia.

Quotas and Slot Sales.—Setting a quota on the number of slots available at an airport is another controversial approach to controlling airport demand. Limits on the number of operations or slots per hour are based on the capacity of the ATC system, the airport runways, and sometimes local sensitivities to noise. Slots at most airports are allocated through negotiations with a scheduling committee consisting of the airlines, the air traffic controllers, the airport management, and DOT. For example, at Washington National, where 60 slots are available per hour, 37 are allocated to air carriers, 11 to commuters, and 12 to GA aircraft. The system allows some flexibility for accommodating more flights in good weather.

Slot sales are an experiment, initiated by DOT, to allocate airport access through bidding. By auctioning slots, DOT provides access to those users willing to pay the highest price. Some economists argue that if airport access must be limited, it should be treated as a scarce resource and priced accordingly.

Critics claim the current slot sale process gives an advantage to the airlines already operating at the airport and denies access to competitors, providing the existing users with virtual monopolies and a financial windfall. The airlines that control the slots contend that the system is fair; since they took the risk necessary to develop the market, they should be rewarded by retaining the slots. Contrary to DOT's expectations, the slot sale plan has not fostered an active market; available slots are scarce and expensive, with 30 minute slots at Washington National and LaGuardia recently selling for over $1 million each.

Restrictions on aircraft by size or type and any form of a quota system used to achieve greater airport efficiency raise important equity issues. Whose access is restricted and why? Is the commuter airline denied access to the nearest hub airport because of its small size or lack of funds to buy a slot? Will smaller communities lose air service entirely because, shut out of hub airports, the commuter airlines that serve them cannot stay in business? Will the airlines increase peak hour fares if airports charge premium fees at peak hours, or will the increased costs be spread among all the airline users to maintain competitive pricing for popular travel times? Experience to date with slot sales raises questions about how fairly market allocation of scarce resources like airport access can work.

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[16] *Aviation Week & Space Technology*, "Massport Passes First Phase of Fee Increases at Logan," Mar. 21, 1988, p. 75.

Effects of Consolidations on Employees

Since 1985, all the major airlines have been involved in some sort of consolidation, creating uncertainty, stress, and dislocation for many employees. Long-term employees accustomed to a secure, regulated environment have been particularly affected. The exact extent to which airline employee performance has been affected by stress related to mergers and takeovers is beyond the scope of this report. However, research indicates that reorganization is always stressful and often debilitating to employees and destructive to company morale. Airline employees have had to deal with wage cuts, relocations, and the threat of job loss. Once confident employees see career paths stymied and disturbing changes in operating practices and the corporate culture.

Psychologically, most employees of companies in the process of management changes go through a series of stages, called the "merger syndrome." After initial denial of the inevitability of change, they approach the consolidation with fear and anxiety, feelings that are replaced by anger and distrust if the merger does not go well.[17] In the last stages, employees leave or adapt through a combination of accommodation and resignation. Even in situations of "friendly" mergers, employees become absorbed and preoccupied with the reorganization. Job performance lags, and attention turns to preparing resumes and talk about personal plans.[18] Some employees suffer from physical symptoms of insomnia, excessive nervousness, and decreased attention span.

Stress and anxiety can be exacerbated by the way the reorganization is managed. Usually, the preliminary negotiations between merging firms are held in secret, giving rise to negative rumors and feelings of helplessness among employees. When the content of the talks is disclosed, information usually centers on the legal and corporate financial matters—not the human concerns preoccupying the employees. Press reports often highlight the problems associated with the consolidation, and accurate answers to questions about the merger are difficult to obtain. In most cases, the details that concern employees have to be worked out in the months after the sale or merger.

Once the merger begins, the problems become more complex, and the most important contributor to company discord and stress is the clash in corporate cultures. Employees and management focus on the differences in the way the two companies operate. Competition develops over whose practices will become the new company policy, and hostility pits executives against each other.[19] The major airlines include several examples of reorganizations that have been as acrimonious and as stressful as any in other industries,[20] as well as mergers that have been relatively harmonious.

Federal Labor Policy Changes

During the 40 year stewardship of CAB, airline employees were cushioned from the stressful changes associated with mergers and other forms of consolidation. CAB routinely conditioned its approval of mergers and acquisitions upon carrier acceptance of a standard set of labor protective provisions (LPP). LPPs addressed the concerns that cause the most anxiety, such as displacement, dismissal, relocation allowances, severance pay, and benefits continuation. Also, LPPs established rules for the integration of seniority lists, work rule practices, and, most significant, wage schedules. While CAB did not have explicit authority to impose LPPs, courts held that it was within CAB's purview to impose them as part of its public interest test.[21]

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[17] M.L. Marks and P.H. Mirvis, "The Merger Syndrome," *Psychology Today*, October 1986, p. 38.

[18] Ibid.

[19] Ibid., p. 41.

[20] OTA confidential airline survey.

Upon assuming CAB's functions in 1985, DOT restricted use of LPPs in light of the government's more limited role in the airline industry. The current policy requires LPPs only when special circumstances prevent the establishment of fair wages and equitable working conditions or if a strike arising from a reorganization would cause a threat to the entire air transportation system. Since adopting these criteria, DOT has not required acceptance of LPPs as a condition for merger approval, arguing that airline employees should be protected from the adverse effects of mergers through collective bargaining negotiations.[22] However, critics point out that this stringent standard virtually precludes LPPs, and that labor agreements cannot adequately protect workers because the contracts may not survive the merger or acquisition process. Defenders of DOT policy maintain that LPPs distort the market system, adding costs that could delay or preclude some reorganizations. They view attempts to require LPPs as steps toward re-regulation of the industry.

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[21] Linda LeGrande, Congressional Research Service, "Airline Mergers and Labor Protective Provisions," issue brief 87179, updated periodically.

[22] Ibid.

PUBLIC POLICIES AFFECTING AIRLINE OPERATIONS

In addition to deregulation, other public policies have had profound impacts on airline operations and safety programs. The President's decision to fire the striking air traffic controllers in 1981 and cutbacks in the FAA inspection work force necessitated by budget cuts in domestic programs represent policy decisions that affected the aviation safety system. Local government decisions restricting airport traffic and airport development for noise control and other reasons stem from the conflict between local goals to provide adequate, safe airport service and to minimize environmental problems.

Air Traffic Controller Strike in 1981

In August 1981, President Reagan fired the 11,345 air traffic controllers who went out on an illegal strike, illustrating how an executive decision made for national labor policy reasons can profoundly affect a vital safety system. The impact of the firing on labor management relations nationwide was profound, setting the tone for widespread reductions in union wages and benefits in many industries. However, the firing of the controllers compounded existing ATC system problems stemming from obsolete equipment and the increases in airline operations at the busiest airports. FAA had not [illegible]mated accurately the increase in the demand for service nor foreseen the impact that the shift to hub and spoke operations would have on its work force and system efficiency.

While FAA began rebuilding its work force immediately after the strike, the loss of two-thirds of its 16,000 controller cadre seriously affected its ability to handle traffic. The ATC system operated at about 80 percent of the pre-strike traffic level with a work force of about 9,000. To handle growing airport traffic with a reduced staff, FAA took steps to spread the work load so that individual controllers would not be overwhelmed by high volume peaks in traffic. It established a system of slot allocations and a reservation system to limit GA access to the ATC system. A system of centralized traffic management, "flow control," was implemented to help reduce airborne delays and keep the demand even and within system capacity. Aircraft separation was increased from 3 miles to 5 miles in the airport area, and from 5 miles to about 30 miles in en route travel, and FAA made extensive use of controller overtime. Some of these actions are still in effect today.

Federal Budget Cutbacks and FAA Inspection Program

While the airline industry was growing at an unprecedented rate, budget constraints forced government-wide cuts in Federal spending. In 1979, approximately 645 inspectors were assigned to 178 air carriers. To comply with national budget goals, the administration cut the inspector work force by 12 percent in 1982 and 1983, a time when the number of airlines grew over threefold. The inspector cut-back had a particularly severe impact on routine safety inspection programs because staffing priority went to conducting new certification inspections. Moreover, FAA was particularly vulnerable to staff cuts, because it lacked staffing standards to justify the number of inspectors needed, and the number of FAA inspectors fell from 3.6 per airline in 1979 to 1.4 in 1983.

The agency began to rebuild the inspector work force in 1984, hiring enough additional inspectors to offset attrition and to restore the work force to the 1981 level. Currently, the inspector work force is above 1981 levels, but is less experienced. Inspector training is of uneven quality, and the cost of living in major metropolitan areas makes attracting high quality personnel difficult, according to FAA regional officials.

Environmental Concerns

As air traffic has increased, so has citizen concern over environmental issues, including those related to airport development and use. (See chapter 3 for a discussion of the institutional relationships of airports to local governments.) By far the most contentious environmental issue is the impact of airport noise on residential neighborhoods. Because the public is very sensitive to noise and increasingly vocal about its concerns, noise is probably the most powerful constraint on airport operations and construction of new facilities.

Although the use of quieter jets can reduce the level of citizen outrage, the issue of airport noise has a permanent place in the public agenda. Local politicians can attest that the mere mention of increases in airport noise can excite constituents into protest action like few other issues. The noise problem is particularly troublesome for busy, metropolitan airports that gradually have been surrounded by development. Operations at most airports have increased in recent years, and some flight paths have been changed, magnifying the noise problem substantially for residential neighborhoods.

To reduce their liability for nuisance and damage claims from noise or at the mandate of local government, airport authorities have instituted noise abatement programs. Among the most effective, but expensive, approaches is the purchase by the airport of surrounding residential property, as the Los Angeles Airport has done. Other techniques more frequently used include restricting aircraft flight paths (which must be done carefully, with safety concerns in mind), the volume of traffic, or the hours of operations based on acceptable noise standards. Some facilities are experimenting with a noise budget, a plan in which the airport is limited to generating a maximum daily decibel total. Airport management can allocate the noise as it sees fit, raising intergovernmental jurisdictional issues and potentially shifting the noise problem to other communities.

The proliferation of local noise ordinances and standards also raises equity concerns. Such regulations could restrict airport access to propeller aircraft or those airlines financially able to purchase quieter jets.

CONCLUSIONS

Currently the airline industry has achieved one of the key characteristics of an oligopoly; through hub control, the power of CRS booking, and codesharing arrangements, a small number of major carriers dominate the market. This fact, which runs counter to the policy objectives of deregulation, has associated tradeoffs for public safety policies. First, the industry climate is likely to be more stable, and although the drive for profits will continue, the intense pressure to cut costs across-the-board may be less. Second, large airlines can be expected to have the resources and management capability to standardize equipment, institute uniform operational procedures and promote policies within their operation that may enhance safety. When a major absorbs a regional carrier it sometimes upgrades the smaller carrier's policies and procedures. The goal of one expansion-oriented major airline is to standardize its regional carriers so that they all follow the same procedures, use the same training methods and eventually fly the same type aircraft, thereby developing a work force of pilots and mechanics trained and experienced in the same aircraft.[23] Finally, having only one dominant airline at an airport could reduce congestion and stress on the ATC system. Lacking intense competition for prime takeoff and landing times, a single carrier has the flexibility to schedule flights to maximize efficiency rather than for a competitive position.

However, nothing guarantees that any safety advantages will be realized; furthermore, gains in stability must be balanced against equity considerations and the goals of public convenience, open entry, and price competition. Unless action is taken to intervene, it is likely that the airline industry will continue to drift toward increased concentration, fewer new entrants, and less price competition. Factors contributing to this trend include noise control or demand management restrictions imposed on the ATC system and airport use, or by constraints that make competition difficult for new firms or for existing firms offering new services. **OTA concludes that Federal decisions that impose ATC or other restrictions for safety reasons may have severe economic consequences for airlines in financial straits. Such decisions thus require careful consideration and active public debate.**

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[23] OTA primary research.

Chapter 3

Regulatory and Institutional Framework

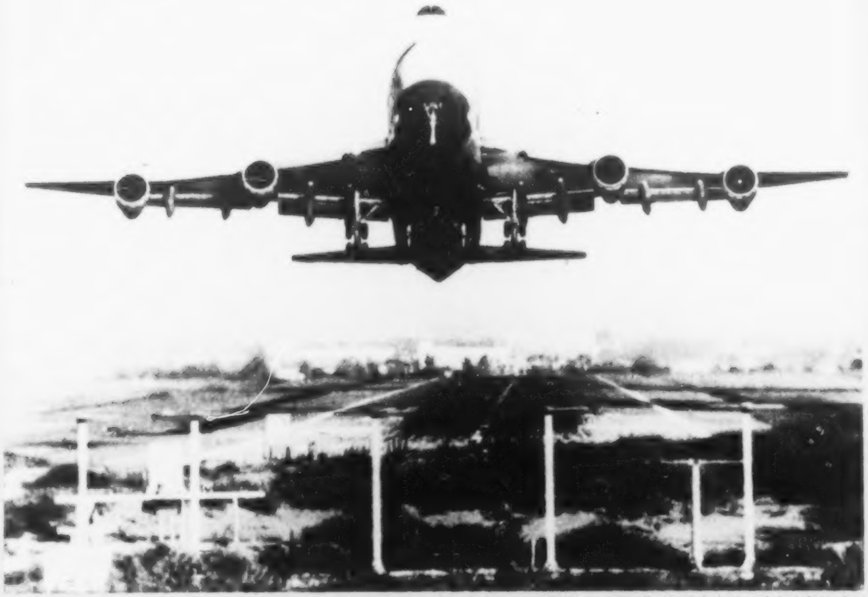

Photo credit: Federal Aviation Administration

CONTENTS

Page
How It All Began 45
  Air Mail Service 45
  Early Safety Initiatives 46
  The Beginning of Economic Regulation 47
  An Expanding Federal Role 47
  Industry Expansion 48
  Responding to Industry Growth 48
  Airline Deregulation 50
Federal Aviation Safety Structure 52
  FAA Responsibility 52
  Other Federal Safety Roles 54
  FAA Funding 54
  Organizational Issues—System Safety Management 54
FAA Regulatory Program 56
  The Office of Airworthiness 56
  Office of Flight Standards 56
  Regulatory Program Issues 58
  Adequacy of FAA Minimum Standards 59
  The FAA Rulemaking Process 59
Air Traffic Control Issues 60
FAA Technology Development Issues 61
  Manpower and Training Needs 62
Airport Issues and Safety 62
  Local Control of Airports 63
  Airport Noise 63
  Land Use Policies and Airport Capacity 64
Conclusions and Policy Options 65

Boxes

Box *Page*
3-A. A Regulatory Enigma: When is a Commuter an Air Carrier and When is it an Air Taxi? 50
3-B. Overview of the FAA Regulatory Program 56
3-C. A Case Study: 747-400 Passenger Exit Doors 57

Table

Table *Page*
3-1. Selected FAA Employee Totals, 1978-87 52

Chapter 3

Regulatory and Institutional Framework

The Federal Aviation Administration (FAA) has a dual mandate: ". . . to promote safety of flight . . . in air commerce through standard setting . . ." and to encourage and foster the development of air commerce.[1] The Airline Deregulation Act, passed in 1978 to encourage industry competition, removed Federal controls over routes, fares, and new entries, but left unaltered the FAA's responsibility for commercial aviation safety. Events of the past decade have shown that neither Congress nor the executive branch fully comprehended the complexity of regulating a newly competitive industry. Although commercial aviation maintains an enviable safety record, dramatic growth in air travel, major changes in technology and industry operations and structure, the firing of the air traffic controllers, and Federal budget constraints have left FAA scrambling to catch up. Consequently, public attention has again focused sharply on whether FAA has the institutional capability and resources to carry out its operating, standard setting, rulemaking, and technology development functions effectively and to guarantee compliance through its inspection programs.

Before 1978, the relative stability of the commercial airline industry made carrying out FAA's regulatory activities less contentious. Industry changes occurred slowly, fewer carriers were competing for the travel dollar, and the costs of required safety improvements could be passed quickly to the consumer. Today's environment is dramatically different, forcing FAA to oversee an industry in which major players come and go, and airlines must expand markets and control labor and other operating costs carefully or go bankrupt. One consequence is that aircraft manufacturers and airlines scrutinize critically any changes of safety regulations, especially those requiring expensive new technology or additional personnel training. Moreover, Federal policies have explicitly discouraged new regulation, unless judged cost-effective, while local government policies have restrained new airport development. This chapter provides an overview of the evolution of Federal aviation safety laws and regulations, describes the current institutional framework, provides analyses of the FAA safety programs, and the impact of local regulations on airport use and development.

HOW IT ALL BEGAN

The roots of today's aviation safety programs, including their rough edges, extend back to the early days of aviation in the mid-1920s. Early commercial uses of aircraft included advertising, aerial photography, crop dusting, and carrying illegal shipments of liquor during Prohibition. Initial efforts to establish scheduled passenger service were short-lived, as service catered primarily to wealthy east coast tourists and was expensive relative to the country's well developed rail and water travel networks.

Air Mail Service

Growth of commercial aviation was greatly stimulated by the establishment of the U.S. Air Mail Service in the early 1920s. Regulations established by the Post Office Department required its pilots to be tested and to have at least 500 hours of flying experience and set up aircraft inspection and preventive maintenance programs. These early regulatory requirements improved air mail carrier safety—in 1924, commercial flyers experienced one fatality per 13,500 miles, while the Air Mail Service had one fatality per 463,000 miles.[2]

In 1925, Congress enacted the Air Mail Act, authorizing the Post Office Department to transfer air mail service to private operators. Twelve carriers, some of which evolved into today's major airlines,

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[1] Public Law 85-726.

[2] Nick A. Komons, *Bonfires to Beacons* (Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, 1978), p. 25.

Photo credit: Smithsonian Institution

An air traffic controller is on duty at the first radio-equipped air traffic control tower at the Cleveland, Ohio airport in 1930.

began air mail operations in 1926 and 1927. These carriers offered limited passenger service, which was much less profitable than carrying mail.[3] Small independent operators, using Ford and Fokker trimotor airplanes, handled most of the passenger service in the late 1920's, the forerunners of today's commuter airlines and air taxis.

Early Safety Initiatives

No Federal safety program existed, prompting a number of States to pass legislation requiring aircraft licensing and registration. In addition, local governments of all sizes enacted ordinances regulating flight operations and pilots, creating a patchwork of safety-related requirements and layers of authority. Modern versions of these difficulties are discussed later in this chapter. Despite strong industry support for Federal legislation, Congress was unable to reach agreement on the scope and substance of a statute until 1926,[4] when the Air Commerce Act was passed.[5] The new law charged the Department of Commerce with both regulatory authority over commercial aviation and responsibilities aimed at promoting the fledgling industry. The major provisions of the act authorized the regulation of aircraft and airmen in interstate and foreign commerce; provided Federal support for charting and lighting airways, maintaining emergency fields, and making weather information available to pilots; authorized aeronautical research and development programs; and provided for the investigation of aviation accidents. Local governments were left with jurisdiction over airport control.

Within the Department of Commerce, a new Aeronautics Branch, comprised of existing offices already engaged in aviation activities, was formed to oversee the implementation of the new law. Nine district offices of the Regulatory Division of the Aeronautics Branch were established to conduct inspections and checks of aircraft, pilots, mechanics, and facilities, and share licensing and certification responsibilities with the Washington, DC office. The basic allocation of responsibilities survives to this day, although the Department of Commerce responsibilities now rest with the Department of Transportation (DOT) and its arm, FAA.

The first set of regulations was drafted with substantial input from aircraft manufacturers, air transport operators, and the insurance industry. Compared with current standards, pilot requirements were minimal; in addition to written and flight tests, transport pilots were required to have 100 hours of solo flight experience, while industrial pilots needed only 50 hours.

Current procedures for certifying aircraft and engines also originated under these early regulatory programs. Aircraft manufacturers were required to comply with minimum engineering standards issued by the Department of Commerce in 1927, and one aircraft of each type was subject to flight testing to obtain an airworthiness certificate for the type.

The Aeronautics Branch also collected and analyzed data from aircraft inspection reports, pilot records, and accident investigations. These data were made accessible to the insurance industry, allowing the development of actuarial statistics. A direct consequence of this step was a significant reduction in insurance rates for many carriers. However, the Department of Commerce, cognizant of its role to promote the aviation industry, was reluctant to make public disclosures about the results of individual accident investigations, despite a provision in the 1926 act directing it to do so. Eventually, in 1934, the Air Commerce Act was amended, giving the Secretary of Commerce extensive powers to investigate accidents, including a mandate to issue public reports of its findings.[6] This congressional policy decision put safety considerations ahead of protecting the industry's image.

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[3] Initially, air mail contractors were paid a percentage of postage revenues. In 1926, however, an amendment to the Air Mail Act of 1925 required payment by weight carried.

[4] Key issues debated by Congress included whether to separate military and civil aviation activities, what responsibilities should be left to State and local governments, and how to provide Federal support for airports. Komons, op. cit., footnote 2, pp. 35-65.

[5] *Congressional Record*, 69th Cong., 1st sess., May 20, 1926, 9811.

As additional regulations to improve safety were implemented, accidents involving passenger carriers and private aircraft decreased significantly; between 1930 and 1932, the fatality rate per 100 million passenger-miles declined by 50 percent.[7] Updated regulations established more stringent requirements for pilots flying aircraft in scheduled interstate passenger service, including flight time limitations.[8] Other requirements specified the composition of flight crews, established standards for flight schools, improved takeoff and landing procedures, set minimum flight altitudes and weather restrictions, and required multi-engine aircraft to be capable of flying with one inoperative engine. In addition, certification of carriers providing scheduled passenger service in interstate commerce commenced in 1930. Although financial data were not examined by the Department of Commerce, standards for key personnel, the ground organization of a carrier, maintenance procedures, and aircraft equipment and instruments had to be met.[9]

The Beginning of Economic Regulation

During the 1930s, industry expansion and the development of aircraft and communication technologies required continuous improvements of regulations, airways, and airports. However, budget constraints prevented the Department of Commerce from conducting sufficient inspections and keeping up with airway development needs. Moreover, a series of fatal accidents in late 1935, 1936, and 1937, including one in New Mexico that killed a New Mexico Senator, called into question the adequacy of existing regulations.[10]

The Civil Aeronautics Act of 1938 marked the beginning of economic regulation. It required airlines, with or without mail contracts, to obtain certificates authorizing service on specified routes, if the routes passed a test of public convenience and necessity.[11]

The Act created the Civil Aeronautics Authority (CAA), which was responsible for safety programs and economic regulations, including route certificates, airline tariffs, and air mail rates. Within CAA, a separate Administrator's Office, answering directly to the President, was responsible for civil airways, navigation facilities, and controlling air traffic.[12] However, in June 1940, under the Reorganization Act of 1939, CAA was transferred back to the Department of Commerce and the Civil Aeronautics Board (CAB) was created and made responsible for regulatory and investigatory matters.

An Expanding Federal Role

Federal responsibilities for airway and airport development grew tremendously during World War II, leading to passage of the Federal Airport Act of 1946, and initiating Federal financial assistance to States and municipalities. The Federal Government assumed responsibility for air traffic control (ATC) at this time. However, the inspector force could not keep pace with the rapidly increasing numbers of new airplanes, pilots, and aviation-related facilities. As early as 1940, CAA had designated certain parts of the certification process to industry. For example, flight instructors were permitted to certificate pilots, and a certificated airplane repaired by an approved mechanic could fly for 30 days until it was checked by an available CAA inspector. After the war, CAA limited its aircraft certification and inspection role to planes, engines, and propellers; manufacturers became responsible for ensuring that other aircraft parts met CAA standards.[13]

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[6] R.E.G. Davies, *Airlines of the United States Since 1914* (Washington, DC: Smithsonian Institution Press, 1972), p. 201.

[7] Komons, op. cit., footnote 2, p. 124.

[8] Pilots were restricted to flying 100 hours per month, 1,000 hours during any 12-month period, 30 hours for any 7-day period, and 8 hours for any 24-hour period; a 24-hour rest period was also required for every 7-day period. These requirements, established in 1934, and virtually the same today, upgraded earlier restrictions which limited pilots to 110 hours of flight time per month. In addition, a waiver of the 8-hour limitation for a 24-hour period could also be granted by the Department of Commerce. The 8-hour waiver rule was ultimately eliminated following a fatal accident involving a pilot who had exceeded 8 hours of flight, and pressure from the Air Line Pilots Association. Ibid, pp. 290-292.

[9] Ibid, pp. 116-118, and Davies, op. cit., footnote 6, p. 201.

[10] The fatality rate rose from 4.78 per 100 million passenger-miles in 1935 to 10.1 per 100 million passenger-miles in 1936. Komons, op. cit., footnote 2, p. 295.

[11] Civil Aeronautics Act of 1938, Public Law 75-706.

[12] Increasing air traffic between Newark, Cleveland, and Chicago prompted a group of airlines to establish an air traffic control system in 1934. By 1936, however, the Department of Commerce assumed control of the system and issued new regulations for instrument flight. Komons, op. cit., footnote 2, p. 312.

Decentralized Management.—Regulatory and organizational changes also took place during and after the war. Regional offices of CAA, reduced in number to seven in 1938, became more autonomous in 1945. Regional officials became directly responsible for operations in their regions, although technical standards and policies were still developed in Washington, DC. Except for a brief return to more centralized management in the late 1950s, regional autonomy within FAA has persisted to this day, slowing communications between and among headquarters and the regions and intensifying inequities in regulatory applications.

Updating Regulations.—Fatal crashes in the late 1940s and early 1950s prompted revised standards setting minimum acceptable performance requirements, designed to ensure continued safe flight and landing in the event of failure of key aircraft components. These standards also distinguished small and large airplanes based on existing airplane and powerplant design considerations; small airplanes were those with a maximum certificated takeoff weight of 12,500 pounds or less, while airplanes above 12,500 pounds were defined as large.[14] This distinction is still applied by FAA today, despite significant changes in aircraft design.

Industry Expansion

Beginning of Air Taxi Service.—Surplus war transport airplanes and a new supply of pilots led to the development of the nonscheduled operator or air taxi. Exempt from economic regulation by the Civil Aeronautics Act of 1938, these operators transported persons or property over short distances in small airplanes, often to locations not serviced by the certificated airlines. CAA, at the time sympathetic to private and small operators, applied less stringent safety regulations to air taxis.[15] In 1952, exemption from economic regulation became permanent, even for carriers using small aircraft to provide scheduled service.[16]

Certificated Airlines.—The decade following World War II witnessed enormous industry growth. Pressurized aircraft traveling at greater speeds and carrying more passengers were introduced.[17] In addition to scheduled passenger service, air freight operations expanded when CAB granted temporary certificates of public convenience and necessity to four all-cargo airlines in 1949.[18] Certification and operating rules for commercial operators—those offering contract air service for compensation or hire—were also adopted in 1949.[19]

Responding to Industry Growth

However, despite continuing increases in air traffic and the need for better airports to accommodate larger and faster aircraft, Federal support for ATC facilities, airport development, and airway modernization was insufficient. CAA, faced with budget reductions in the early 1950s, was forced to abandon control towers in 18 small cities and numerous communications facilities, postpone jet development and navigation improvements, and curtail research efforts. The Federal airport development program, championed by cities and smaller municipalities, was embroiled in controversy. In addition, the number of CAA regional offices was reduced from 7 to 4, 13 safety inspection field offices were eliminated, and the industry designee program was expanded.

The impending introduction of jet aircraft and a 1956 midair collision over the Grand Canyon involving a DC-7 and a Super Constellation helped promote congressional authorization of increased levels of safety-related research and more Federal inspectors. In 1958, Congress passed the Federal Aviation Act establishing a new aviation organization, the Federal Aviation Agency.[20] Assuming many of the duties and functions of CAA and CAB, the Agency was made responsible for fostering air commerce, regulating safety, all future ATC and navigation systems, and airspace allocation and policy. CAB was continued as a separate agency responsible for economic regulation and accident investigations.[21]

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[13] John R.M. Wilson, *Turbulence Aloft: The Civil Aeronautics Administration Amid Wars and Rumors of Wars, 1938-1953* (Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, 1979), p. 152.

[14] Ibid, p. 261; and 43 *Federal Register* 46734 (Oct. 10, 1978).

[15] Wilson, op. cit., footnote 13, p. 161.

[16] The Civil Aeronautics Board adopted 14 CFR 298, designating an exempt class of small air carriers known as "air taxis."

[17] Initially, Lockheed produced the Constellation which carried 60 passengers and was 70 mph faster than the DC-4. To compete with Lockheed, Douglas developed the DC-6. Subsequently, upgraded versions of each aircraft—the DC-7 and the Super Constellation—were introduced. Davies, op. cit., footnote 6, p. 289.

[18] The four carriers were Air News, Flying Tigers, Slick, and U.S. Airlines. See Nawal K. Taneja, *The Commercial Airline Industry* (Lexington, MA: Lexington Books, D.C. Heath and Co., 1976), p. 6.

[19] 44 *Federal Register* 66324 (Nov. 19, 1979).

[20] Public Law 85-726, Aug. 23, 1958, 72 Stat. 731.

The safety provisions of the 1958 act, restating earlier aviation statutes, empowers the Agency to promote flight safety of civil aircraft in air commerce by prescribing:[22]

- minimum standards for the design, materials, workmanship, construction, and performance of aircraft, aircraft engines, propellers, and appliances;
- reasonable rules and regulations and minimum standards for inspections, servicing, and overhauls of aircraft, aircraft engines, propellers, and appliances, including equipment and facilities used for such activities. The Agency was also authorized to specify the timing and manner of inspections, servicing, and overhauls and to allow qualified private persons to conduct examinations and make reports in lieu of Agency officers and employees;
- reasonable rules and regulations governing the reserve supply of aircraft, aircraft engines, propellers, appliances, and aircraft fuel and oil, including fuel and oil supplies carried in flight;
- reasonable rules and regulations for maximum hours or periods of service of airmen and other employees of air carriers; and
- other reasonable rules, regulations, or minimum standards governing other practices, methods, and procedures necessary to provide adequately for national security and safety of air commerce.

In addition, the act explicitly provides for certification of airmen, aircraft, air carriers, air navigation facilities, flying schools, maintenance and repair facilities, and airports.[23]

In the years following creation of the Agency, Federal safety regulations governing training and equipment were strengthened despite intense opposition from industry organizations. The number of staff members also grew in the early 1960s, and inspection activities were stepped up, including en route pilot checks and reviews of carrier maintenance operations and organizations.[24]

In 1966, the Federal Aviation Agency became the Federal Aviation Administration, when it was transferred to the newly formed Department of Transportation (DOT).[25] The National Transportation Safety Board (NTSB) was also established to determine and report the cause of transportation accidents and conduct special studies related to safety and accident prevention; accident investigation responsibilities of CAB were moved to NTSB.

Renewed support for improvements to airports, ATC, and navigation systems was also provided by the Airport and Airway Development Act of 1970. The act established the Airport and Airway Trust Fund, financed in part by taxes imposed on airline tickets and aviation fuel, and was reauthorized in 1987.[26]

Recognizing that existing industry descriptors, such as trunks, locals, and commuters (see box 3-A), were no longer appropriate, CAB redesignated scheduled passenger airlines into the following groups based on annual revenues:

- major airlines (above $1 billion);
- national airlines ($75 million to $1 billion);
- large regional airlines ($10 million to $75 million); and
- medium regional airlines (up to $10 million).[27]

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[21] However, the Federal Aviation Administration Administrator was authorized to play an appropriate role in accident investigations. In practice, the Federal Aviation Administration routinely checked into accidents for rule violations, equipment failures, and pilot errors. Moreover, the Civil Aeronautics Board delegated the responsibility to investigate nonfatal accidents involving fixed-wing aircraft weighing less than 12,500 pounds to the Federal Aviation Administration. Stuart I. Rochester, *Takeoff at Mid-Centry: Federal Aviation Policy in the Eisenhower Years, 1953-1961* (Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, 1976), p. 234.

[22] 49 U.S.C. 1421(a).

[23] See 49 U.S.C. 1430, 1422-1424, 1426, 1427, and 1432. Procedures for amending, suspending, or revoking certifications are contained in 49 U.S.C. 1429.

[24] Federal Aviation Administration staff grew from 30,000 in 1959 to 40,000 in 1961. Rochester, op. cit., footnote 21, p. 295.

[25] U.S. Department of Transportation Act, Public Law 89-670, 49 U.S.C. 1651.

[26] For additional information on implementation problems associated with the Trust Fund, see J. Glen Moore and Patricia Humphlett, Congressional Research Service, "Aviation Safety: Policy and Oversight," Report #86-69SPR, May 1986.

[27] U.S. Department of Transportation, Federal Aviation Administration, *FAA Handbook of Statistical Information, Calendar Year 1986* (Washington, DC: 1987), p. 118.

Airline Deregulation

Prompted by widespread dissatisfaction with CAB policies and the belief that increased competition would enhance passenger service and reduce commercial airline fares, Congress enacted the Airline Deregulation Act of 1978.[28] Specifically, the act phased out over a 6-year period CAB control over carrier entry and exit, routes, and fares. In 1984, the remaining functions of CAB were transferred to DOT. These functions include performing carrier fitness evaluations and issuing operating certificates, collecting and disseminating financial data on carriers, and providing consumer protection against unfair and deceptive practices.[29]

During the 60-year history of Federal oversight, Federal regulatory and safety surveillance functions have been frequently reorganized and redefined. Moreover, public concerns about how FAA carries out its basic functions have remained remarkably

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[28] Public Law 95-504, 92 Stat. 1703. It was thought that fares would drop based on the record of intrastate airlines where fares were 50-70 percent of the Civil Aeronautics Board-regulated fares over the same distance. In addition, the Civil Aeronautics Board had already reduced restrictions on fare competition in 1976 and 1977 and allowed more airlines to operate in many city-pair markets. Robert M. Hardaway, "Transportation Deregulation (1976-1984): Turning the Tide," *Transportation Law Journal*, vol. 14, No. 1, 1985, p. 136.

[29] Civil Aeronautics Board Sunset Act of 1984, Public Law 98-443, Oct. 4, 1984, 98 Stat. 1703.

Box 3-A.—A Regulatory Enigma: When is a Commuter an Air Carrier and When is it an Air Taxi?

Federal regulations define and set requirements for commuters using a confusing variety of different and overlapping definitions. The Airline Deregulation Act of 1978 made the term "commuter" virtually meaningless in commercial aviation—in fact, the former Commuter Airline Association of America changed its name to the Regional Airline Association. Currently, the two broad categories of commercial aviation transportation are: 1) certificated air carriers, and 2) air taxi operators. Commuters are categorized as air taxi operators that provide passenger service for at least five round trips per week between two or more points.[1] Previously, the Civil Aeronautics Board (CAB) designated as commuters those scheduled operators of aircraft with 30 or fewer seats who were not certificated under Section 401 (public convenience and necessity) of the Federal Aviation Act. Since deregulation, however, the economic definition of commuter was raised to operators of aircraft with 60 seats or fewer. Consequently, many airlines identified now as commuters operate under the same safety regulations as major jet carriers, following their training and experience rules for pilots, and maintenance and airworthiness requirements for aircraft.

Operations

The primary safety regulations governing airline operations are 14 CFR 121 (air carrier) and 135 (air taxi operator). Airlines providing service with aircraft designed to carry more than 30 passengers or over 7,500 pounds of cargo must adhere to the more stringent Part 121 rules. Differences between Parts 121 and 135 include training, experience, and work hours for pilots, and maintenance and safety equipment for aircraft. As operating rules are the key determinant in aviation safety, the National Transportation Safety Board and the Federal Aviation Administration's (FAA) Associate Administrator for Aviation Standards use Parts 121 and 135 as broad categories for classifying accidents and other safety statistics, and OTA followed suit in this study.

Airworthiness

Airworthiness standards for aircraft used in Part 121 and Part 135 operations are divided into two main sections—Part 23 for small airplanes and Part 25 for large transport category airplanes. In 1953, the dividing line between small and large airplanes was set at 12,500 pounds, regardless of type of operation. However, over time, commercial aircraft weighing just under 12,500 pounds proliferated. In 1987, FAA established a commuter category of aircraft with 19 or fewer passenger seats and takeoff weight of 19,000 pounds or less, and amended airworthiness requirements in Part 23 to cover this category. Appendix A of Part 135 includes additional airworthiness requirements for commuter aircraft with 10 to 19 seats. Aircraft with at least 20 seats are certificated under Part 25 (but aircraft that operate under Part 121 with fewer than 20 seats must be certificated under Part 25). Before 1987, commercial aircraft with up to 30 passenger seats were certificated under special conditions or Special Federal Aviation Regulation numbers 23 and 41. These were intended to provide relief to the industry and constant despite a steadily improving aviation safety record. OTA's brief historical summary demonstrates that:

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[1] 14 CFR 298.2.

- Specifically authorized by legislation after lengthy debate in the 1950s, industry participation in regulatory activities has a long history. Responsible Federal aviation agencies consistently have designated part of the certification and inspection processes to the private sector, specifically certification of pilots, aircraft parts, and aircraft repair. This reliance on private industry is heaviest when national budget constraints lead to shortages of Federal inspectors and technical expertise.
- From the initial 1926 legislation to the 1978 Deregulation Act, Congress has charged Federal agencies with the dual responsibilities of maintaining aviation safety and promoting the industry which history shows are not always compatible. Furthermore, except for a 2-year period from 1938 to 1940, Federal regulatory and enforcement functions have been combined in one agency.
- Federal aviation regulatory enforcement activities have always been decentralized with regional and district offices having considerable autonomy and independence from Washington headquarters.
- More stringent safety standards usually follow a widely publicized airline accident and vocal public and congressional concern, rather than

public from lack of suitable certification procedures and standards while FAA developed permanent rules.

Economic Fitness and Reporting

Federal economic regulatory provisions and traffic and financial reporting requirements for air carriers also depend on aircraft size: 14 CFR 217 and 241 govern operations of aircraft with maximum capacity greater than 60 passengers, and 14 CFR 298 covers smaller aircraft. While all airlines certificated under Section 401 must meet certain economic fitness requirements, those that operate small aircraft (60 seats or fewer) have greatly reduced data reporting requirements. In 1952, Part 298 established a class of small air carriers exempt from economic regulation called "air taxi operators." CAB designated as "commuters" those air taxi operators that offered scheduled passenger service. While commuters must meet the same safety standards as small certificated air carriers, they have fewer traffic and financial data reporting requirements than the certificated airlines. Other air taxi operators report no data under Part 298.

Nonregulatory Differences

Air traffic controllers use yet another set of terms for classifying airlines. In compiling statistics on the users of air traffic control (ATC) services, controllers categorize aircraft as air carriers (commercial aircraft larger than 60 seats), air taxis (all other commercial users), military, or general aviation (all other aircraft). Commuters are not differentiated in ATC traffic statistics. Since many air taxis operate small single engine aircraft, controllers often count them as general aviation aircraft unless otherwise identified by a flight plan or aircraft livery.

Until 1986, FAA statistics on near midair collisions grouped aircraft in three categories only: air carrier, general aviation, and military. Under this grouping, all commercial aircraft are air carriers, although FAA now subcategorizes air carriers as large air carriers, commuters, and air taxis.

Federal Standards for Commuter Airlines[a]

	Large airline	Small airline
Operations	Part 121	Part 135
Airworthiness	Part 25	Part 23
Economic fitness and reporting	Parts 241 and 217	Part 298

Commuter airlines must comply with large airline regulations for:[c]	Aircraft size (in passenger seats)[b]				
	1-9	10-19	20-30	31-60	61+
Operations	—	—	—	X	X
Airworthiness[d]	—	—	X	X	X
Economic fitness and reporting[e]	—	—	—	—	X

[a] Airlines that provide scheduled short haul passenger service in propellor-driven aircraft with fewer than 61 seats are considered generally to be commuters.

[b] Aircraft size can be classified also by payload weight, but is not shown here.

[c] Regulations for large airlines are the most stringent in each category; a commuter or other small airplane operator can choose to follow them when they are not mandatory.

[d] If an airline follows large airline operating rules, then the aircraft, regardless of size, flown under those rules must meet the airworthiness standards for large transport category aircraft.

[e] If an airline has one or more aircraft in service with more than 60 passenger seats, then the airline must adhere to large airline data reporting requirements for every aircraft in its fleet.

SOURCE: Office of Technology Assessment, 1988.

from FAA initiatives. Recent examples include legislation enacted in late 1987 of collision avoidance equipment requirements for commercial aircraft and broadened altitude encoding transponder requirements for general aviation aircraft.

FEDERAL AVIATION SAFETY STRUCTURE

FAA Responsibility

Since Congress dismantled CAB, FAA has been the chief regulator of the U.S. airline industry, with some political and analytic support from other parts of DOT. The task is formidable. On the one hand, the agency must stand up to intense pressure from DOT and industry on proposed regulatory changes, and, on the other, address constant public and congressional anxieties about safety and convenience. FAA's effectiveness has been undercut by budget constraints affecting personnel and procurement, equipment obsolescence, inadequate, long-range, comprehensive planning, and problems with its inspection and rulemaking programs. (Table 3-1 shows the impacts of budget constraints on personal levels in critical areas.) Furthermore, local governments play major roles in determining airport operations and development, often conflicting with FAA goals. Only an agency with strong leadership and singleness of purpose and responsibility could maintain a steady course under such conflicting pressures.

Although all FAA sections have safety related activities, responsibility for the largest safety programs is under the purviews of the Associate Administrators for Air Traffic, Aviation Standards, and Development and Logistics. Also, all nine regional offices have broad and separate authority, as does the Mike Monroney Aeronautical Center in Oklahoma City. This splintering of authority has long been recognized as creating fundamental organizational problems within FAA and in its relationship to Congress, DOT, and industry.

- *Aviation Standards*. Headquartered in Washington, Aviation Standards manages field offices in charge of both airworthiness standards for aircraft and regulations for all air carrier operations. The Aviation Standards National Field Office, located in Oklahoma City, has responsibility for a variety of support activities, including management of national safety databases and conduct of standardization training for designated examiners. Aviation Standards also receives technical support from the FAA Technical Center in Atlantic City, New Jersey, for regulatory development and for research and testing related to crashworthiness and fire safety.
- *Air Traffic*. Through the regions, Air Traffic is responsible for operation of the 20 Air Route Traffic Control Centers, 176 Terminal Radar Approach Control facilities, hundreds of airport towers, the Central Flow Control Facility, plus Flight Service Stations located throughout the United States and Puerto Rico. In addition, Air Traffic formulates plans and requirements for future ATC operations, and evaluates and analyzes current ATC operations.
- *Development and Logistics*. Development and Logistics is in charge of technology development, implementation, and maintenance, and

Table 3-1.—Selected FAA Employee Totals, 1978-87

Occupation	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Air traffic controller[a]	16,750	16,853	16,584	6,658	11,416	11,946	11,944	12,245	12,429	12,847
Aviation safety inspector[b]	1,466	N/A	1,499	1,615	1,423	1,331	1,394	1,475	1,813	1,939
Electronics technician[c]	9,423	9,209	8,871	8,432	8,031	7,633	7,229	6,856	6,600	6,740

[a] Full performance level and developmental controllers at towers and centers.

[b] Air carrier inspectors (approximately 40 percent of the total) were responsible for 145 air carriers, while general aviation inspectors were responsible for 173 Part 135 commuter airlines, 7,804 other commercial aircraft operators, and 5,210 aviation schools and repair stations as of Mar. 10, 1988.

[c] Communications, navigational aid, radar, and automation technicians.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration data as follows: controller data as of September 1987; inspector data as of March 1988; and technician data as of March 1988.

Photo credit: Federal Aviation Administration

FAA air traffic controllers in the control tower during the annual International Experimental Aircraft Association Convention and Aviation Exhibition handle 400 takeoff and landing operations per hour.

has overall responsibility for the National Airspace System (NAS) Plan. Offices within Development and Logistics include Automation Service, which is in charge of upgrading the ATC system and implementing the Advanced Automation System. Program Engineering Service directs other NAS Plan programs, and Systems Engineering Service handles system engineering for the NAS Plan, advanced systems and concepts, and development of the NAS Performance Analysis Capability for system-wide airspace management. Systems Maintenance Service directs maintenance of the NAS. The FAA Technical Center performs engineering and testing for NAS Plan developments, in support of Development and Logistics.

Within FAA, two additional groups have explicit safety responsibilities.

- *Aviation Safety.* Reporting directly to the FAA Administrator, Aviation Safety coordinates accident investigations, safety analyses, and special studies. Aviation Safety monitors safety activities of FAA programs, but does not function effectively as support to the operations of these programs.
- *Mike Monroney Aeronautical Center.* Located in Oklahoma City, the Center houses the FAA Academy, the Civil Aeromedical Institute (CAMI), the Aviation Standards National Field Office, and the Airway Facilities National Field Support Center. The Academy is the principal training facility for air traffic controllers. The Aviation Standards Training Branch at the Academy trains flight standards and airworthiness inspectors, flight inspectors, and other personnel who work in Aviation Safety. CAMI researchers focus on improving selection and

training for air traffic controllers, medically related aspects of aviation, including controllers' performance in the field, and physiological studies of pilot performance.

Other Federal Safety Roles

Other DOT offices oversee economic regulatory activities previously performed by CAB.

- The Office of the Secretary of Transportation (OST) issues certificates of public convenience and necessity required for all new carriers. OST also convenes government/industry meetings when necessary to handle scheduling peaks and delays.
- The Office of Aviation Operations and Aviation Enforcement and Proceedings in the General Counsel's Office performs fitness tests that examine a new carrier's management capability, financial posture, and regulatory compliance record.
- The Office of Aviation Information Management in the Research and Special Programs Administration collects economic information from major, national, regional, and commuter airlines as required especially under 14 CFR 241 and 14 CFR 298.

The National Transportation Safety Board.—Although not a regulatory agency, NTSB is an important institutional part of the safety structure. Created in 1966 as an arm of DOT, it became an independent executive branch agency in 1975. In addition to investigating commercial transport accidents, NTSB conducts special safety studies and issues recommendations that often call for rule revisions or for new Federal regulations and procedures to correct safety problems. FAA conducts its own review of accidents and is not bound to accept NTSB suggestions for regulatory changes.

FAA Funding

Federal Government funding for aviation-related programs comes from two sources: the Airport and Airway Trust Fund and from general tax revenues. The trust fund is financed by excise taxes on the aviation industry and its users, including an 8 percent ticket tax on commercial air passenger transportation within the United States. In addition, the unused portion of the trust fund accumulates interest credit payments from the Treasury. Currently, the largest contributor to the trust fund is the ticket tax, which accounted for 69 percent of the trust fund in 1985, followed by interest payments. Aviation excise taxes are deposited in the general fund of the Treasury. Although trust funds accounted for about 70 percent of FAA's total budget in fiscal year 1985, FAA consistently spends less out of the trust fund than is taken in from excise taxes and interest payments on the balance in the trust fund. Consequently money accumulates in the Treasury, where, according to current Federal accounting standards, it can be counted against the Federal deficit.[30] Critics of this policy believe the full resources of the fund should be available to FAA for operation and research and development rather than used as a tool to reduce the Federal deficit figures.

Organizational Issues—System Safety Management

Notable in this brief description of FAA safety offices is the absence of a strong, internal system safety management advocate. A comprehensive approach to system safety could be described as:

> The application of engineering and management principles, criteria, and techniques to optimize safety within the constraints of operational effectiveness, time and cost throughout all phases of the system life cycle.[31]

Basic system safety management principles are applicable to commercial aviation and to the National Airspace System. A comprehensive system safety management program for FAA would apply to all aspects of planning, data collection and analysis, engineering, and operations. For example, the economic health and management stability of an airline strongly influence its ability and willingness to bear the cost of such safety activities as recurrent cockpit resource management and weather training for pilots, internal safety audits, and standardizing equipment and procedures. Yet while different offices within FAA have recognized the importance of all these factors, the agency has not systematized procedures to incorporate them in all areas of its oversight activities. Human error, the leading cause of commercial aviation accidents, also receives little FAA attention (see chapter 6). These shortcomings speak to a need for coherent integrated safety management at FAA, beyond the development and enforcement of individual regulations and specific programs targeted at isolated problems.

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[30] U.S. Congress, General Accounting Office, *Aviation Funding: Options Available for Reducing the Aviation Trust Fund Balance*, GAO/RCED-86-124BR (Washington, DC: U.S. Government Printing Office, May 1986).

[31] U.S. Department of Defense, *Military Standard: System Safety Program Requirements*, MIL-STD-882B (Washington, DC: Mar. 30, 1987).

In the absence of FAA system safety capability, this function is partially performed by groups such as Congress and airline labor unions, especially on issues where powerful interest groups differ vehemently (such as altitude encoding transponders). However, effective safety management is highly technical and requires continual close, objective attention to system-wide needs. These are beyond the capability of such groups.

System safety principles are also applicable to the NAS Plan, throughout all phases of its evolution and development of its elements, such as ATC technologies. NAS Plan programs often encompass some elements of system safety analysis. For example, the Traffic Alert/Collision Avoidance System (TCAS) program includes modeling and analysis of the effects of TCAS-induced maneuvers on air traffic, and other efforts to try to identify hazards in the use of TCAS before it is fully implemented. Procedural changes in the terminal area are evaluated through "worst case" scenarios, operational judgment of experienced controllers, and other means, in an attempt to prevent accidents. These efforts are commendable, but maintaining or improving air safety as traffic levels increase will require a more systematic and broader approach to safety management. FAA's Office of Aviation Safety is developing system safety standards for FAA procurements based on military system safety standards. This is a good first step, but commitment will be needed to incorporate the principles fully into FAA's rigid technology development process, and, beyond that, into the entire life cycles of NAS.

The ATC system and supporting technologies warrant immediate special attention from a system safety perspective. The ATC system is currently under severe pressure to extend its operations to the limits of safe practice to meet the demand for service at busy hub airports. Furthermore, while the need to modernize ATC facilities is widely recognized, FAA's current plans include advanced automation features that are difficult to justify on the basis of efficiency and raise important human-factor questions (see chapter 7). Rigorous system safety management, both for the near term and the longer term, would help maintain the excellent accident record of the ATC system, as FAA rises to the challenge of managing higher traffic levels. Resources are required for near-term ATC needs, such as increasing personnel levels and upgrading the computers in Terminal Radar Approach Control facilities. These are needed to accommodate increases in traffic and transponder users. Attention to formulating a better system safety groundwork for the more advanced parts of the system is also important.

Internal Communications

An additional and related problem is internal FAA communication paths. As shown in figure 3-1, vertical lines of communication exist between the Administrator and the programs under the purview of the Associate Administrators and with the nine regional offices. However, the chart also illustrates that 22 separate groups report to the Administrator and that no formal lines of communication are apparent among the operating programs and within program divisions. Moreover, even when communication lines exist, they are often ineffective because of timing and rigidity of responsibilities. For example, under the Associate Administrator for Development and Logistics, individual program managers in two offices are responsible for meeting milestones in the development and implementation of NAS subsystems. A third office is responsible for defining requirements and ensuring that individual subsystems combine effectively to form an overall system. Because many of the programs in the NAS Plan are already well underway by the time requirements are defined and validated, program managers have difficulty refocusing away from milestones and responding efficiently to inputs from other groups.

Within the last 15 years, FAA has had seven administrators, serving an average of 2 years. Although this length of term is not unusual for Administration appointees, this high rate of turnover highlights a central concern about FAA's capability to perform its safety mission—the requirement for long-range planning and policy commitment. Since many of FAA's responsibilities involve long-range programs, such as the modernization of equipment and facilities, the absence of consistent leadership is severely felt.

FAA REGULATORY PROGRAM (see box 3-B)

Although largely unnoticed by the traveling public, Federal safety regulations, administered by FAA, establish the basic safety structure for U.S. aviation. Regulatory and oversight functions are primarily housed under the Associate Administrator for Aviation Standards, and activities of two of its offices are critical during times of major industry change.

The Office of Airworthiness

The Office of Airworthiness has two prime functions: to establish minimum standards for the design and manufacture of all U.S. aircraft and to certify that all aircraft meet these standards prior to introduction into service. Airworthiness standards prescribe explicit flight, structural, design and construction, powerplant, and equipment requirements.

Box 3-B.—Overview of the FAA Regulatory Program

Federal Aviation Regulations are divided into 2 major parts:

- Part 121 applies to scheduled operations of large aircraft (more than 30 seats or a payload capacity greater than 7,500 lbs.)
- Part 135 regulates small aircraft (30 seats or fewer or a maximum payload capacity not over 7,500 lbs.)

The two principal regulatory programs are administered through nine FAA regional offices (see figure 3-1) and are directed by:

- Office of Airworthiness, which certificates aircraft and equipment.
- Office of Flight Standards, which governs all aspects of carrier operations.

The regulatory process has three components:

- Rulemaking to establish minimum standards, Federal Aviation Regulations.
- Inspections to certificate new carriers and to monitor compliance.
- Enforcement if noncompliance is found.

The office issues "type"[32] certificates to prototype aircraft built in conformance to airworthiness standards after successful testing. Manufacturers try to ensure that individual aircraft conform to the type to obtain FAA airworthiness certification. If major changes are made in an aircraft design, a new type certificate is required. However, if less extensive changes are made, FAA amends a type certificate and issues a supplemental one. As pilots must have additional and expensive training to operate a new type of aircraft, manufacturers and airlines prefer continuous supplemental certificates and pilot type ratings.

Four FAA regional offices have certification authority for aircraft and certain systems:

- Central Region (Kansas City) certificates general aviation aircraft.
- New England Region (Boston) certificates engine and propulsion systems.
- Northwest Mountain Region (Seattle) certificates large commercial aircraft.
- Southwest Region (Fort Worth) certificates helicopters.

This decentralized management lends itself to internal FAA disagreements over regulatory actions and sometimes outright contradictions (see box 3-C for details).

Office of Flight Standards

Commercial aircraft are spot checked by Flight Standards inspectors to ensure they comply with Federal Aviation Regulations. This office certifies that new air carriers meet Federal standards and approves flight procedures, determines some equipment regulations, and is responsible for seeing that inspectors conduct routine safety inspections.

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[32] 14 CFR 1.1 (Jan. 1, 1987).

Box 3-C.—A Case Study: 747-400 Passenger Exit Doors

A long simmering controversy over regulations on exit doors of large transport aircraft illustrates the interaction of FAA regulatory offices, industry, union groups, Congress, and the legal system. The controversy began in 1983 when Boeing Aircraft Co. proposed to modify some inservice 747 aircraft by sealing off two passenger exit doors over the wings. The modification expanded the section for business class passengers and reduced the cost penalty for carrying and maintaining the exits. Boeing intended to supply airlines with kits to make the modification if they desired and to offer its new 747-400 model with the overwing exit doors in place, but closed off.

Current regulations require one pair of Type A exits (large exits each side of the fuselage in all locations on the 747) per 110 passengers; no restrictions are placed on spacing between the exits or between passengers and exits.[1] Boeing planned to restrict the number of passengers to 440 on the 747 when it removed the overwing exits, to ensure that the aircraft complied with regulations. The Northwest Mountain region of FAA, responsible for aircraft certification, approved the change in 1984.

The approval caused an outcry from cabin attendants' unions, including the Association of Flight Attendants, who informed FAA they intended to ask Congress to intervene on grounds of diminished safety. After the resultant publicity, Thai International Airlines started reinstalling overwing exits on its modified 747s.[2] The FAA Administrator wrote to the Chief Executive Officers of U.S. airlines recommending overwing doors not be sealed off even though the configuration was certified by FAA. The Administrator subsequently announced his position at a hearing before the House Public Works and Transportation Subcommittee on Investigations and Oversight, much to the surprise of other high ranking FAA officials. U.S. carriers have followed his advice, possibly out of fear of litigation if there were a crash. However, some foreign carriers have sealed off their exits.

Despite the Administrator's recommendation, Boeing has been marketing an eight-exit configuration for its 747-400. FAA has written a Notice of Proposed Rulemaking that would require no more than 60 feet between exit doors and no more than 30 feet between any passenger and a door. If approved, the rule would not permit 747-400 certification with eight exits. Also, it would exclude foreign-owned 747s with eight exits from operating within the United States.

FAA maintains that the current regulations do not specify a distance between doors and that Boeing is stretching the limits of the current regulations too far.[3] Boeing maintains that a rule change at this point is unjustified and that evacuation tests and limited accident data show the eight-door configuration meets current requirements for evacuation of the plane and thus is adequate from a safety standpoint.[4] Boeing filed suit on September 9, 1987, in the 9th Circuit Court of Appeals in San Francisco, asking the Court to review an FAA order disapproving type certification of the 747-400. FAA reaffirmed its position at a hearing of the House Public Works and Transportation Subcommittee on Investigations and Oversight on March 2, 1988.

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[1] 14 CFR 25.807 (Jan. 1, 1987).

[2] Bron Rek, "Escape From Burning Cabins: Are Smoke Hoods the Answer?" *Interavia*, vol. 42, January 1987, pp. 37-38.

[3] Melvin C. Beard, director, Office of Airworthiness, Federal Aviation Administration, personal communication, Aug. 26, 1987.

[4] Robert A. Davis, 747 chief project engineer, Boeing Commercial Airplane Co., letter to OTA, Oct. 13, 1987.

FAA inspections are divided into three functional categories:

- Operations, including minimum equipment lists, pilot certification and performance, flight crew training, and in-flight recordkeeping.
- Maintenance, including maintenance personnel training policies and procedures for overhaul, inspection, and equipment checks.
- Avionics, specializing in aviation-related electronic components.

Usually, each airline is assigned a principal inspector for each of the three categories of inspections. The principal functional area inspectors are assisted by inspectors from one of the 90 FAA district offices within whose boundaries the airline operates. In addition to certificating new airlines and performing routine inspections, FAA principal inspectors are responsible for investigation and enforcement duties.[33]

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[33] U.S. Congress, General Accounting Office, *Report on Aviation Safety: Needed Improvements in FAA's Airline Inspection Program are Underway*, GAO/RCED 87-62 (Washington, DC: May 1987), p. 12.

Regulatory Program Issues

In the years just prior to deregulation, standards and procedures followed by major U.S. airlines often exceeded minimum Federal requirements. However, starting in 1978, economic forces exerted great pressure on redundancies in industry safety programs, eliminating some and intensifying the importance of strong Federal enforcement programs. At the same time, FAA's capability to monitor the industry was swamped by problems, which were in part products of executive branch policies and governmental budget constraints, and which were independent of deregulation, although deregulation magnified their impact.

Investigations conducted since 1983 by FAA itself, the General Accounting Office (GAO), and NTSB cited weaknesses in the FAA inspection programs. OTA research confirms that severe difficulties persist, although work is underway to standardize procedures and provide for greater flexibility in personnel assignments.

Criticism of the FAA inspection program generally focuses on three categories: manpower and training, information systems, and management control. Manpower problems became acute during the early years of deregulation when Federal budget constraints required cuts in the inspector work force. At the end of fiscal year 1978, FAA had 1,580 Flight Standards field office inspector positions authorized, and actual employment was 1,466. By fiscal year 1981, the authorization had risen to 1,748, and 1,615 inspectors were "on board" on September 30, 1981. Three years of deep budget cuts reduced the authorization by 18 percent to 1,440 inspectors by the end of fiscal year 1984. (Actual employment on September 30, 1983, was 1,331 inspectors.) At the end of fiscal year 1978, there were 556 "air carrier" inspectors employed (605 authorized) which increased to 623 (674 authorized) by the end of fiscal year 1981, and fell to 507 (569 authorized) by the end of fiscal year 1983. The planned end of fiscal year 1984 authorization was 508, later increased to 674 (the 1981 high). Thus, while the number of airlines was rapidly rising in the years following deregulation (the number of commercial operators roughly doubled between 1979 and 1983), the number of air carrier field inspectors in FAA was rapidly declining. Inspectors were shifted from routine operations and maintenance inspections to airline certifications. FAA's end-of-year goal for fiscal year 1988 is 2,088 field office inspectors, and FAA plans to add about 285 inspectors in each of fiscal years 1989, 1990, and 1991.[34]

Moreover, even if numbers of newly hired inspectors reach adequate levels, FAA inspector training programs cannot keep up with new industry procedures and equipment, such as contract maintenance work and new cockpit technologies. Training is most problematic in areas of recent technological development, such as advanced composite materials used by aircraft manufacturers, new navigational systems, and other computerized systems.[35] As aircraft and technologies become more complex and sophisticated, training for inspectors will become even more critical.

Furthermore, FAA managers have long lacked current and reliable information on allocation of inspectors and inspection records, leading to inconsistencies among FAA district offices, and inadequate followup to inspection activities. Shortages of computerized equipment and lack of high quality core training at the Oklahoma City Academy exacerbate information difficulties.

Traditionally, FAA has delegated broad authority to regional and district offices concerning the frequency and scope of inspections. FAA regional offices stoutly reaffirm the importance of meeting regional needs at the regional level, leaving general policy guidance to Washington. However, FAA headquarters has never effectively centralized management control to permit evaluating regional and district inspection activities, to ensure uniformity in policies and procedures, and analyze inspection findings on a national scope. Wide variations in the number and kind of inspections performed from region to region identified by GAO in 1985, still persisted according to OTA's research.[36]

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[34] Anthony J. Broderick, associate administrator, Aviation Standards, Federal Aviation Administration, personal communication, Mar. 31, 1988.

[35] General Accounting Office, op. cit., footnote 33, p. 50.

[36] U.S. Congress, General Accounting Office, *Compilation and Analysis of the Federal Aviation Administration's Inspection of a Sample of Commercial Air Carriers*, RCED-85-157 (Washington, DC: Aug. 2, 1985); and OTA primary research.

The competence and professionalism in the manufacturing and operating industries ensure airworthiness of commercial aircraft to current standards, and past history shows that industry safety standards are almost always high. FAA needs adequate technical expertise and records to be able to target the rare cases where standards are not sufficiently high, as well as knowledge about industry management attitudes and financial stability.

To improve management of its inspection responsibilities over the long term, FAA initiated Project SAFE, a program to establish staff standards, increase staff levels, improve inspector manuals and training courses, and establish performance standards for each FAA regional office. Task forces made up of headquarters and regional staff are revising and standardizing inspection manuals and training policies. Needed improvements to training courses in Oklahoma City and standardizing of regional on-the-job training are planned under Project SAFE, but are moving at a snail's pace. Moreover, emphasis on monitoring individual airline characteristics, such as compliance records, fleet composition, management changes, and financial stability, would permit FAA to allocate its inspector resources more effectively.

Adequacy of FAA Minimum Standards

The recent major airline crash in Denver and a spate of commuter accidents focus attention not only on inspection programs, but also on the adequacy of FAA minimum safety standards. Although most airlines maintain standards above the minimum required by FAA, some safety officials are concerned that the minimum may not be adequate in some instances. Because of such concerns, the Department of Defense has instituted a safety program that frequently uses a higher standard in selecting contract airlines than the minimum standards required by FAA.

In response to the 1985 crash of a military chartered DC-8 in Gander, Newfoundland, the Military Traffic Management Command (MTMC) and the Air Force Military Airlift Command (MAC) overhauled their inspection program and established an Army/Air Force Central Safety Office to coordinate standard setting and inspection activities. Enforcement actions against the airlines are the responsibility of a military review board.[37] The MTMC/MAC office conducts inspections, in addition to FAA's, of all airlines used for military charters. During the 2 years since the Gander crash, the safety office has disqualified 13 U.S. airlines and taken lesser disciplinary actions against 9 others. Poor maintenance practices and failure to comply with airworthiness directives are the most frequent problems. Half of the cited airlines were large carriers operating under Part 121.

By the summer of 1988, the MTMC/MAC safety program will be supported by a new database. The Air Carrier Analysis System (ACAS) will compile and analyze data on airline accidents, incidents, maintenance and operating problems, and financial characteristics. The system will alert inspectors to those circumstances at an airline that warrant personal inspections and provides a useful model for FAA, which is cooperating with MTMC/MAC.[38] However, ACAS relies upon FAA databases which are incomplete and are not designed to support analyses.

The FAA Rulemaking Process

Prior to deregulation, FAA had considerable regulatory autonomy, overseeing an industry in which profits were protected through the extensive rate and entry rules of CAB. Over the past decade, vigorous industry economic competition has made rulemaking a distinctly adversarial process. Carriers, labor groups, aircraft manufacturers, and general aviation supporters carefully scrutinize every proposed safety regulation and question its efficacy and impact on costs. Often such activities, in concert with administrative policies and bureaucratic labyrinths, have effectively blocked safety regulations for years.

Presidents Ford, Carter, and Reagan each initiated progressively stronger and more centralized programs of regulatory review in response to concerns about the excessive burdens and inadequate management of Federal regulations. These policies, implemented explicitly through Executive Orders in 1981 and 1985, direct agencies to:

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[37] James Ott, "Military Avoids U.S. Carriers That Fail Safety Standard," *Aviation Week & Space Technology*, Feb. 8, 1988, pp. 99-101.

[38] Ibid; and Broderick, op. cit., footnote 34.

- base their regulatory rulemaking decisions on benefit-cost analyses,
- submit new regulations for review by the Office of Management and Budget (OMB),[39]
- refrain from starting work on any significant new regulation until consulting with OMB, and
- publish in the annual Regulatory Program a status report on each significant regulatory initiative.

While all executive branch agencies have had to revamp their regulatory procedures as a result of these Executive Orders, FAA has faced a special challenge because proposed remedies to safety risks often entail expensive technological developments requiring long lead times.

Moreover, DOT has gone substantially beyond Executive Order mandates for economic review of proposed rules for all its modal agencies. Cost-benefit analyses are required only for identified "major" regulations, but in contrast to some other executive branch agencies, DOT expanded this requirement to include "significant" rules, a category that covers nearly all regulations.[40]

For FAA, the review process now consists of the following major steps:

- FAA advises the Office of the Secretary of intent to start work on a significant regulation. DOT departments register concerns about the proceeding or about analysis needed.
- A team of FAA staff members develops a new rule proposal.
- A member of FAA's Office of Aviation Policy, who also serves on the rule-drafting team, prepares the cost-benefit analysis.
- After FAA approval, the regulatory package, complete with economic analysis, moves to DOT's General Counsel Office for a required departmental review, including Assistant Secretaries for Policy and International Affairs, Government Affairs, and Budget and Programs.
- Prior to public release, the General Counsel mediates OMB's review of the regulation and economic analysis.

In a major review of its regulatory program in 1984, FAA identified over 100 regulations needing revision. Twenty-six regulations were assigned high priority status and are currently in various stages of the process; another 85 form a large backlog. Long backlogs can lead to "immediate action" regulations and inspector handbook changes that alter regulations without adequate due process. While FAA plans a rewriting of Part 121 and 135 regulations, this major undertaking will require years of intensive effort.[41]

AIR TRAFFIC CONTROL ISSUES

In the aftermath of the controller's strike and concurrent with its effort to even out traffic flow, FAA began to rebuild the controller work force by hiring, training, and certifying new controllers at an accelerated pace. Anticipating a more efficient controller work force as a result of NAS Plan improvements (see chapter 7) and believing that the prestrike work force was overstaffed, the administration established a target work force goal of 14,306, lower than the pre-strike level. Also, believing that the pre-strike controllers were more qualified than necessary, FAA lowered the goal of full performance level controllers to 75 percent from 80 percent.

FAA has succeeded in achieving some of the goals of its recovery schedule but not all. The primary goal of FAA's recovery plan was to return to 100 percent of pre-strike traffic level, with flow control in place, by June 1983. This target was met on schedule, but goals to reduce the extensive use of flow control and to have controllers return to normal work schedules in every facility still elude the agency. Also, supervisors still work traffic during peak hours more and work more overtime hours than before the strike.

The rebuilding process has been slow and tedious. Because of the special aptitudes required for the job, a higher than expected washout rate of new recruits has slowed recovery. Also, retirements, promotions to supervisory jobs, and normal attrition has cost the controller work force many of its most

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[39] Thomas Hopkins, "Aviation Safety Rulemaking," OTA contractor report, August 1987, p. 5.

[40] Ibid, p. 7.

[41] General Accounting Office, op. cit., footnote 33, p. 26.

Photo credit: Federal Aviation Administration

FAA air traffic controllers handle traffic in the Dallas-Fort Worth Terminal Radar Approach Control (TRACON) facility.

experienced members, about 500 each year from retirements alone.[42] Training capabilities have been especially hard hit.

The effects of the strike on individual airports varied widely. Some were hardly affected, while others lost most of their work force. In general, the effect was greatest where the union was most active—in Chicago and New York City airports, more than 95 percent of the full performance level controllers struck and were fired. More remote, less demanding facilities had few strikers. The resulting disparity in the geographical distribution of experienced controllers remains a very difficult problem for FAA.

Moreover, even at present, differences in living costs, traffic volume and complexity, and other factors, compound difficulties in filling controller vacancies in major metropolitan areas such as Los Angeles, Chicago, New York, and Boston. In mid-1986, O'Hare airport had 52 vacancies for full performance level controllers. Special FAA programs to attract experienced controllers to these busy facilities have had only limited success, and staffing shortfalls must be met with newly trained recruits. Therefore, the controller work force at some of the busiest airports can be among the least experienced or trained. While FAA has a mandate to increase the air traffic controller work force to 15,800 by October 1988, the increase in total numbers of controllers will not eliminate these particular problems.

FAA TECHNOLOGY DEVELOPMENT ISSUES

Federal acquisitions of major technical support systems are governed by OMB Circular A-109, which divides acquisition into four steps:

- Identification of mission need for a technological system, including some development of cost and schedule goals.
- Identification and exploration of alternative design concepts, followed by demonstration of the concepts.
- Full-scale development and limited production.
- Full-scale production.[43]

However, FAA does not always follow this standard protocol. For example, none of the original 11 major NAS Plan programs adhered to A-109, and all the programs that have reached key decision points have skipped steps in the process. Such shortcuts have led so far to successful deployment of the Host computer system at Air Route Traffic Control Centers only 6 months behind the original schedule. Other programs have slipped far behind schedule and have incurred large cost increases compared to original estimates. Schedule slippage and cost increases are not unusual for large and complex government development programs. However, some NAS Plan delays were incurred because the components as originally conceived could not be completed without additional engineering work and adaptation to the rapidly changing air traffic system. None of these were adequately anticipated in the original plan.

The long-term NAS Plan programs have not met shorter-term needs of the system—these shorter-term needs require the capability for anticipating problem areas and rapid development and operational testing of alternative solutions, in addition to long-term developments.

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[42] Cecilia Preble, "Growth of Air Traffic Raises ATC Staffing Issue," *Aviation Week & Space Technology*, Mar. 31, 1986, p. 44.

[43] U.S. Congress, Office of Management and Budget, "Major System Acquisitions: A Discussion of the Application of OMB Circular No. A-109," OF PP Pamphlet No. 1, August 1976.

Photo credit: Federal Aviation Administration

The FAA's Air Route Surveillance Radar (ARSR-3), used for long-range surveillance, dwarfs its predecessor and provides improved coverage.

Manpower and Training Needs

Manpower, logistics support, and technical training needs were not fully considered in designing the NAS development program. As NAS becomes more fully automated, personnel who maintain NAS equipment and other highly technical programs will require sophisticated training. Also, budget constraints have held down appointments for technicians to maintain NAS systems in the field, of significance because many current technicians will be eligible for retirement soon.[44]

Because contractor maintenance of NAS equipment is not always of sufficient quality, FAA must train technicians. Classroom and laboratory training are done at the FAA Academy, which is not well prepared to meet the needs. The rapid influx of new, automated NAS systems requires rapid development of new training courses and, over time, will require radical changes in requirements for training of field personnel. Field technicians who troubleshoot equipment will be replaced in the future by engineers who monitor system parameters remotely for signs of trouble. This will call for broader, more sophisticated training than is now usually given at the Academy. Capabilities are being developed for more efficient design of training courses, including job task analysis, computer-based instruction, and an automated training development system. Still, the Academy views NAS Plan delays with relief, because they allow more time for training course development.[45] Moreover, instructors' grades at the Academy (GS-12) are not as high as those of automation engineers and systems engineers in the field, and instructors at the Academy are sometimes snubbed for the higher-grade jobs when they return to the field.[46] These conditions are not conducive to more sophisticated training at the Academy.

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[44] Mel Yoshikami, manager, Airways Facilities Division, Federal Aviation Administration, personal communication, Aug. 6, 1987.

[45] Morris Friloux, superintendent, Federal Aviation Administration Academy, personal communication, Dec. 8, 1987.

[46] Richard J. McCarthy, training branch manager, Airways Facilities, Federal Aviation Administration, personal communication, Dec. 14, 1987.

AIRPORT ISSUES AND SAFETY

The Federal role in airport development and management has grown as airports have become increasingly critical links in the Nation's transportation system. In the early years of U.S. aviation, Congress held that airports were not a matter of Federal interest and should be developed and managed locally. Federal responsibility was limited to charting airways, providing lights for night flying, maintaining emergency fields, and furnishing weather reports. However, World War II changed this limited perspective, and national defense became a major rationale for Federal participation in airport development. Congress appropriated $500 million from the general fund for a capital grants program for airport improvements in the Federal Airport Act of 1946.[47] The Federal Aviation Act of 1958 continued the policy of providing support for airport development from the general fund, although Congress was becoming uncomfortable with this type of direct subsidy with general funds.

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[47] U.S. Congress, Office of Technology Assessment, *Airport System Development* (Washington, DC: U.S. Government Printing Office, August 1984), p. 29.

In the Airport and Airway Development Act of 1970, Congress institutionalized Federal airport aid, establishing the Airport and Airway Trust Fund to modernize ATC and support the Airport Development Aid Program (ADAP). The act levied an airline ticket tax and a GA fuel tax to provide a dedicated source of revenue; it also provided grants through ADAP to assist airport operators in funding capital projects. In 1982, Congress reauthorized the Airport and Airways Trust Fund and initiated a new capital grant for airport improvements. Recognizing State and local noise concerns, the act earmarked 8 percent of these new funds for noise abatement projects. In December 1987, Congress reauthorized the Trust Fund, reaffirming support for joint Federal/State/local responsibility for airports.

FAA has always played an important role in the operational side of airport management. Because it owns and operates the ATC system, including many ATC towers, navigational equipment, and landing aids, it directs the flow of traffic in the local airways and in and out of commercial airports. In this capacity, FAA has direct control of and responsibility for air traffic safety. Airport improvements that require installing, moving, or upgrading ATC equipment have to be approved and implemented by FAA. In addition, safety and operational standards for airports, established by FAA, must be followed in projects supported by Federal funds.

Local Control of Airports

Despite an increase in Federal involvement in airport development and operations over the last 20 years, most airports in the United States are locally owned and operated. More than half of the Nation's large and medium commercial airports, and a greater percentage of small commercial facilities are operated by municipal and county governments.[48] A typical municipally operated airport is city-owned and run as a department of the city, with policy direction by the city council or by a separate airport commission or advisory board. Another large group of airports are run by multipurpose port authorities—public corporations that operate a variety of publicly owned transportation facilities such as harbors, toll roads, and bridges. Also, single-purpose authorities operate both medium-size airports and large facilities.

Airport Noise

Noise became a major political and environmental issue in the early 1960s with the widespread introduction of commercial jet aircraft. FAA estimates that the land areas affected by aviation noise increased about sevenfold between 1960 and 1970.[49] Residents living near airports and along flight paths complain that aircraft noise is annoying—especially at night—and depreciates the value of their property. Scientific evidence corroborates that high exposure to noise can lead to high stress levels, nervous tension, and inability to concentrate. Although according to FAA only about 2 percent of the U.S. population is affected by aircraft noise, the noise issue has affected operations at many major airports and is a major factor in constraining airport expansion and development.[50]

Reacting to public outcry, Congress amended the Federal Aviation Act in 1968, requiring the FAA Administrator to take regulatory action to control and abate aircraft noise. To reduce the noise made by aircraft and engines, FAA established maximum noise standards for newly manufactured aircraft engines through FAR part 36. Known as stage 3 aircraft, those that meet the quieter standards are expected to replace existing equipment by the year 2000. FAA grant funds are available for noise abatement programs including purchase of equipment to measure noise, sound proofing nearby buildings, and even the purchase of contiguous property severely affected by aircraft noise.

While FAA supports the concept of local noise abatement programs, it leaves regulating noise to the airport operators. A Federal noise standard could expose the Federal Government to liability for damages if the standards were exceeded. Moreover, restricting air traffic for other than safety reasons conflicts with FAA's mandate to foster air commerce. However, FAA has established guidelines for measuring noise and has suggested methods for determining land uses compatible with various day-night average sound levels. On the other hand, Executive Order 12371 requires that Federal agencies such as FAA, consult and cooperate with local governments in the administration of Federal assistance and development programs. This review and approval power provides local and regional governments with leverage to require adoption of noise standards and to require noise abatement measures as part of a federally financed airport development project.

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[48] Ibid, p. 21.

[49] Ibid, p. 21.

[50] Ibid.

Motivated by political pressure from local residents and the fear of liability claims, airport operators are using their authority—although limited—to control noise. The basic legal ground rules for noise control strategies are that they be nondiscriminatory, do not unduly burden interstate commerce, and have the effect of reducing noise. Finally, noise abatement restrictions must not interfere with safety or the Federal prerogative to control aircraft in the navigable airspace.

Local restrictions on aircraft to reduce noise generally fall into three groups. One strategy is to modify flight paths in cooperation with local ATC staff so that aircraft fly over water, industrial or vacant land, and avoid densely populated areas. Second, local airports can limit the number of flights or the types of aircraft; and third, some airports are experimenting with noise budgets that set a maximum daily decibel total, which the airport allocates among carriers.

Undeniably, noise abatement restrictions reduce airport capacity and can cause delays, sending ripples throughout the air traffic system. Moreover, pilots on tight schedules are tempted to abbreviate check lists and fly above FAA-approved speeds to beat nighttime curfews at their destinations. Some departure and arrival speed and flight path control requirements may adversely affect safety, and FAA needs better analytic tools to help identify the impacts on safety and develop countermeasures for the curfew restrictions. Finally, noise restrictions create equity issues. Although the courts have struck down blatantly discriminatory plans, stringent noise restrictions could force carriers to accelerate fleet replacement.

Land Use Policies and Airport Capacity

The absence of strong, local land use policy to protect existing airports from encroaching development limits the capacity potential of the airport system. Land suitable for airport expansion is either too expensive or unavailable, and hostile neighbors seek to limit the number of existing flights. Ironically, the availability of highway access and utilities required by the airport attracts residential development. In rural jurisdictions on the fringes of metropolitan areas, local officials often do not support land use controls, and airports unprotected by regulations become focal points for development.

Obstacles to Expanded Airport Capacity

Local and regional governments do not find it easy to gain wide public support for long-range commitments to runway and airport planning and construction. During the next 10 years, construction may begin on only two major new airports (a replacement for Denver's Stapleton and a new one at Austin, Texas), and even that modest estimate may not be achieved. The complexity of any airport project requires coordination and agreement among Federal, State, local and regional governments on airport siting and specific development and acquisition plans and projects. To highlight the enormity of land acquisition, the Dallas-Fort Worth Airport required the purchase of 18,000 acres and agreements protecting an additional 4,000.

In short, additional airport capacity is years away, and FAA needs systematic plans to handle safely projected increases in demand, which may include demand management where necessary. The alternative is to accept delays as an inevitable accompaniment to an overburdened system.

CONCLUSIONS AND POLICY OPTIONS

While FAA's dual responsibilities of providing aviation safety and fostering air commerce are not always incompatible, in times of rapid industry change, they present the agency with unavoidable conflicts. **Congress may wish to identify safety as FAA's sole and unique responsibility, especially for ATC and regulatory programs. Responsibility for fostering economic development of the industry could be returned to the Secretary of Transportation.** Given the current growth of the industry, the competitive industry climate, and the constraints on FAA personnel levels and technical expertise, reaffirmation of the primacy of safety could clarify goals for allocating FAA resources. Industry promotion functions are compatible with DOT's economic and consumer protection functions, and DOT staff is better-suited to deal with complex economic and political questions of demand management than the highly trained technical personnel in FAA. Close communication should be maintained so DOT aviation policymakers have the advantage of FAA's technical knowledge and safety expertise.

Many of FAA's problems identified in this chapter have their roots in the bureaucratic culture and are characteristic of most Federal agencies. The lack of agency autonomy over personnel, procurement processes, and budget decisions and its inability to adapt quickly to change are not problems unique to FAA and will exist to some extent regardless of the organizational structure within the government. Undeniably, however, FAA's effectiveness during the recent past has been undercut by national budget problems that have limited the FAA work force in numbers (see table 3-1) as well as levels of technical expertise. **OTA finds that assisting FAA to overcome some of these special difficulties is an important safety priority for Congress to consider. For example, provision for cost of living adjustments for assignments in major metropolitan areas could ease transfer of personnel to facilities with special needs. Mechanisms to speed contracting procedures for training and other vital procurements could be helpful.**

While there is general agreement about the organizational and operational weaknesses of FAA, proposals for reform range widely. The debate over reshaping the Federal Government's oversight bureaucracy centers around these general concepts:

- Length of the Administrator's term.
- Policymaking relationship between DOT and FAA.
- Status of ATC functions. Proposals include contracting ATC service to a private provider, establishing a Federal corporation, and forming a nonprofit, user-owned corporation.
- Status of the Aviation Trust Fund. Debate centers around the unified Federal budget process.

The frequent turnover of Federal administrators works against unified decisionmaking and the implementation of comprehensive long-range planning in every agency, and FAA is no exception. **OTA finds that without stronger leadership, FAA problems of inadequate long-range planning, interdepartmental coordination, management information, and uneven application of regulations by regions are bound to continue. Congress may wish to consider setting a fixed term of up to 5 years for the FAA Administrator.** A seasoned administrator will have a better chance at tackling the bureaucratic problems of procurement and personnel and budget restrictions.

Allocation of agency resources through the budget process requires close coordination with planning goals to ensure support of priority objectives and programs. A strong administrator could establish, through reorganization or management directives, greater control over the regional offices to ensure coordination, consistent policy, and even-handed application of regulations. Organizational changes and management incentives could improve internal communications among operating programs and within program divisions. To keep up with the technological and structural changes in the industry, FAA's rulemaking process needs to be streamlined and safety considerations better integrated into all levels of analysis. As the industry grows and aircraft technologies become more complex and sophisticated, FAA's need for more and better trained inspectors and technical personnel will become even more critical. Equally important is the need for hiring and adequate training of personnel responsible for maintaining the technology of NAS.

To provide accountability for the fixed-term administrator, Congress may wish to require him or her to develop a rolling 5-year agency development plan and to report annually on its status. Based on clearly stated goals and objectives for personnel, technology, and regulations, such a plan could provide Congress with a tool for assessing the agency's progress and a picture of its long-range direction.

Noise issues will continue to constrain airport operations and development. ATC bears the brunt of the safety implications of such local regulations and the impact of increased demand on major hub airports. Advocates of an independent ATC system reason that this large, highly technical operation could be more efficiently managed if separate from the Federal regulatory program. **OTA finds that the ATC function is inextricably linked with aviation safety and is a central component of an integrated FAA safety system.** While Congress has demonstrated its reluctance to alter the current policies pertaining to the use of the Aviation Trust Fund, short-term improvements to ATC to address capacity problems and the need for enhanced FAA technical expertise are immediate needs that could be addressed by resources from the fund. Demonstration by FAA of a plan to use funds specifically for such purposes could help to convince Congress to authorize them. However, other ongoing FAA activities fall under the Federal responsibility for safety in interstate commerce and are appropriately supported by the General Fund. Moreover, FAA could further enhance its technical expertise by better use of existing Federal resources at the National Aeronautics and Space Administration (NASA) and NTSB.

Furthermore, **OTA concludes that FAA needs a strong, comprehensive, internal safety management system to support planning and ensure that the full resources of the agency coordinate and focus on the most important safety issues. ATC improvements, regulatory and enforcement programs, and NAS Plan programs in particular warrant attention from a system safety perspective.** Currently, in the absence of system safety management at FAA, backed by strong technical expertise, safety issues come to Congress and other groups, ill-suited to perform safety management functions.

Although many in the aviation community find DOT intrusive and overly political, DOT represents FAA's interests in the cabinet—especially important during budget formulation—and often provides a balanced policy viewpoint on some issues in contrast to FAA's technical perspective. Moreover, OTA finds that removing FAA from DOT does not by itself address the principal frustrations currently voiced. The sources of these frustrations are twofold: overall Administration policy and internal FAA management problems. OTA concludes that FAA independent of DOT would still be subject to Administration policies, just as NASA is. Furthermore, internal problems must be resolved by and within FAA proper.

Chapter 4

Safety Measurements and Data Resources

Photo credit: Federal Aviation Administration

Air Safety databases are maintained at FAA's computer center in Oklahoma.

CONTENTS

Page

Measuring Transportation Safety 69
  Safety Factors 69
  Exposure Data 70
  Nonaccident Safety Data 71
  Primary Safety Factors 73
  Secondary and Tertiary Safety Factors: Industry Safety Posture 75
Data Resources 77
  Federal Safety Data Resources 77
  FAA 77
  National Transportation Safety Board 84
  NASA 85
  RSPA 86
Conclusions and Options 87

Box

Box *Page*

4-A. Measures of Transportation Safety: Definitions 73

Figure

Figure *Page*

4-1. Commercial Aviation Accident Causal and Preventive Factors 72

Tables

Table *Page*

4-1. Safety Measures and Exposure Parameters 71
4-2. Federal Aviation Safety Databases 78

Chapter 4

Safety Measurements and Data Resources

Transportation accidents account for only 2 percent of all deaths from any cause in the United States annually, and the public readily accepts the existence of travel risk. However, public concern varies for different kinds of risk, and intense attention focuses on air transportation, even though the fatality rate is very low. One reason may be the relative perceptions of being in control of one's destiny—the operator of an automobile feels responsible for his own fate; the passenger on board a public conveyance does not. Nonetheless, more people die in private automobile accidents in an average month in the United States than have died in commercial aircraft accidents during the past 10 years.

A commercial aircraft crash, though a relatively rare event, can result in the simultaneous deaths of hundreds of people and often receives immense public attention, while a similar number of isolated fatalities is hardly noticed. The perceived loss to society is said to be proportional to the square of the number of people killed in a single incident, implying that 10,000 individual deaths are the same as 100 at once, and that public preventive efforts should follow accordingly.[1]

While sometimes irrational about safety, societies do attempt to minimize risk to the extent feasible and at an acceptable cost. Jimmy Doolittle expressed this well in a report in 1952 to President Truman:[2]

> The 'Calculated Risk' is an American concept which gives mobility to the whole structure. The phrase simply means a willingness to embark deliberately on a course of action which offers prospective rewards outweighing its estimated dangers. The American public accepts the calculated risk of transportation accidents as an inescapable condition to the enjoyment of life in a mechanical age. However, the public expects and cooperates to . . . narrow the gap between relative and absolute safety.

To know if risk is being reduced, one must be able to measure it, and the first half of this chapter outlines a theoretical framework for nonaccident safety data analysis. Collecting and analyzing many of these data may not be practical or feasible, however, and the discussion is presented as a guide to current safety data systems and their capabilities. The last sections of the chapter present analyses of existing safety databases and assess their utility and limitations.

MEASURING TRANSPORTATION SAFETY

Safety Factors

In passenger transportation, safety factors are events or procedures that are associated with or influence fatality rates. The probability of death (or injury) as a result of traveling on a given mode, if it can be quantified, is the primary benchmark of passenger transportation safety. To be useful, alternative safety indicators must ultimately be correlated to this benchmark. Vehicle accident rates are also commonly used as safety indicators, since most passenger fatalities occur as a result of vehicle accidents.

If risk is defined as the probability of death, past risk in traveling can be empirically determined from fatality rates. Commercial aviation accidents involving large jets can result in the deaths of hundreds of people; thus, a single accident can significantly influence fatality rates. Consequently, trend analyses of fatality rates require data from time periods of roughly 5 years or more, and these rates give poor indications of short-term changes in risk.

Accident rates can be an alternative to fatality rates as indicators of safety levels. While fatalities are often associated with aviation accidents, the number of fatalities, even for a specific type of accident, fluctuates considerably with each crash. The number of accidents may have a smaller range of yearly variance than the number of fatalities, but

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[1] Albert L. Nichols and Richard J. Zechhauser, "The Perils of Prudence: How Conservative Risk Assessments Distort Regulation," *Regulation*, November/December 1986, pp. 13-24.

[2] Jerome Lederer, "Aviation Safety Perspectives: Hindsight, Insight, Foresight," *Nineteenth Wings Club 'Sight' Lecture*, presented at the Wings Club, New York City, Apr. 21, 1982, p. 3.

Photo credit: National Transportation Safety Board

Major accidents result in tragic losses. Fortunately, such catastrophes are rare.

poses similar analysis problems. For example, midair collisions involving large, commercial jets have occurred twice in the United States during the last 10 years—little can be inferred from these numbers regarding changes in collision risk. Since the number of accidents is small and can vary significantly from one year to the next, accident rates are also poor indicators of short-term changes in risk.

Safety factors other than fatalities or accidents should be considered for prompt feedback on policy decisions or changes in the aviation operating environment. The Federal Government and the aviation industry maintain a wide assortment of safety-related information. However, without consideration of the accuracy, completeness, and original purpose of these databases, safety trend analyses based on this information are meaningless.

Exposure Data

Understanding the measures that are the denominators of transportation accident or fatality rates is necessary for safety analysis. The choice of which exposure data type to use affects how the rates can be compared across and within the transportation modes. Passenger-miles (the number of passengers multiplied by the miles traveled) are the best available exposure parameters for comparing air transportation with other modes and allow broad system comparisons.[3] Risk per passenger-mile is not uniform over a trip, and may vary by routing or time of day. For example, the probability of an accident is significantly higher during takeoff or landing than while flying enroute; thus, most commercial aviation passenger-miles occur during much lower than overall average risk conditions. (For further information, see chapter 5.)

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[3] Trips between specific city pairs would be a better measure, since the relative risks among different modes of travel between two points is the primary safety concern. However, the total number of city pairs in the United States is too large for comparative analysis and passenger data in this form are not readily available for some modes.

Since the number of passengers per vehicle can vary, vehicle-miles are often used to show exposure when comparing accident rates. Risk may not be uniform over each vehicle-mile traveled, and vehicle size and speed do not affect accident risk exposure indicated by vehicle-miles.

An aviation accident fatal to one passenger is likely to be fatal to many on board.[4] Since most of the risk involved with air transportation is associated with takeoff and landing, a 2,000-mile trip is similar to a 200-mile trip when compared for safety. Therefore, the number of trips (departures) is a valid exposure parameter for air transportation, and both passenger-departures (or -enplanements) and aircraft-departures can be used.

Finally, time is a common measure of exposure in many types of risk analyses. Flight-hour data are necessary for economic, operational, and maintenance requirements of aircraft and airlines. Since accurate data are kept, they are readily available as exposure information.

No single measurement provides the complete safety picture (see table 4-1). Passenger exposure data are used when passenger risk is to be indicated, while miles are used when it is important that the exposure data not be influenced by vehicle size or speed. Departure exposure data account for non-uniform risk over a trip. Time is a generic exposure measure in many fields, and data in that form are often readily available.

Nonaccident Safety Data

Accident investigations often uncover pervasive, but unrecognized, causal factors and can help prevent similar accidents from occurring. However, since commercial aviation accidents are so rare, other measures are needed for identifying short-term changes in safety. The goal of nonaccident data analysis is to help prevent the first accident from happening.

Potential safety indicators are measureable factors associated with or causally related to accidents, fatalities, or injuries. Ideally, the amount of data available will be large enough, unlike accident or fatality data, so that random events will have a small effect on yearly trends. The diagram of aviation accident causal and preventive factors (see figure 4-1) identifies sources for some nonaccident safety indicators.

In the diagram, items closely associated with accidents appear near the "accident" box. These offer the greatest potential as safety indicators and are explained in the following sections. Factors more removed from "accidents" have a correspondingly long causal link to them. These factors are measured against more subjective standards and may be more difficult to quantify—"industry policy," for example.

Measurement Methodology

Clear and precise definitions exist for aviation accidents (see box 4-A); the consistent and accurate accident databases pose no problems for analysis from a measurement standpoint. Moreover, in the United States, every commercial aviation accident is tracked by the National Transportation Safety Board (NTSB), providing a complete set of aviation accident and fatality data. However, other indicators require consideration of the measurement meth-

Table 4-1.—Safety Measures and Exposure Parameters

Critical events	Exposure parameters	
Injuries	Passenger-miles	Vehicle-miles
Fatalities	Passenger-hours	Vehicle-hours
Accidents	Passenger-departures (or -enplanements)	Vehicle-departures (or -trips)
Fatal accidents		

SOURCE: Office of Technology Assessment, 1988.

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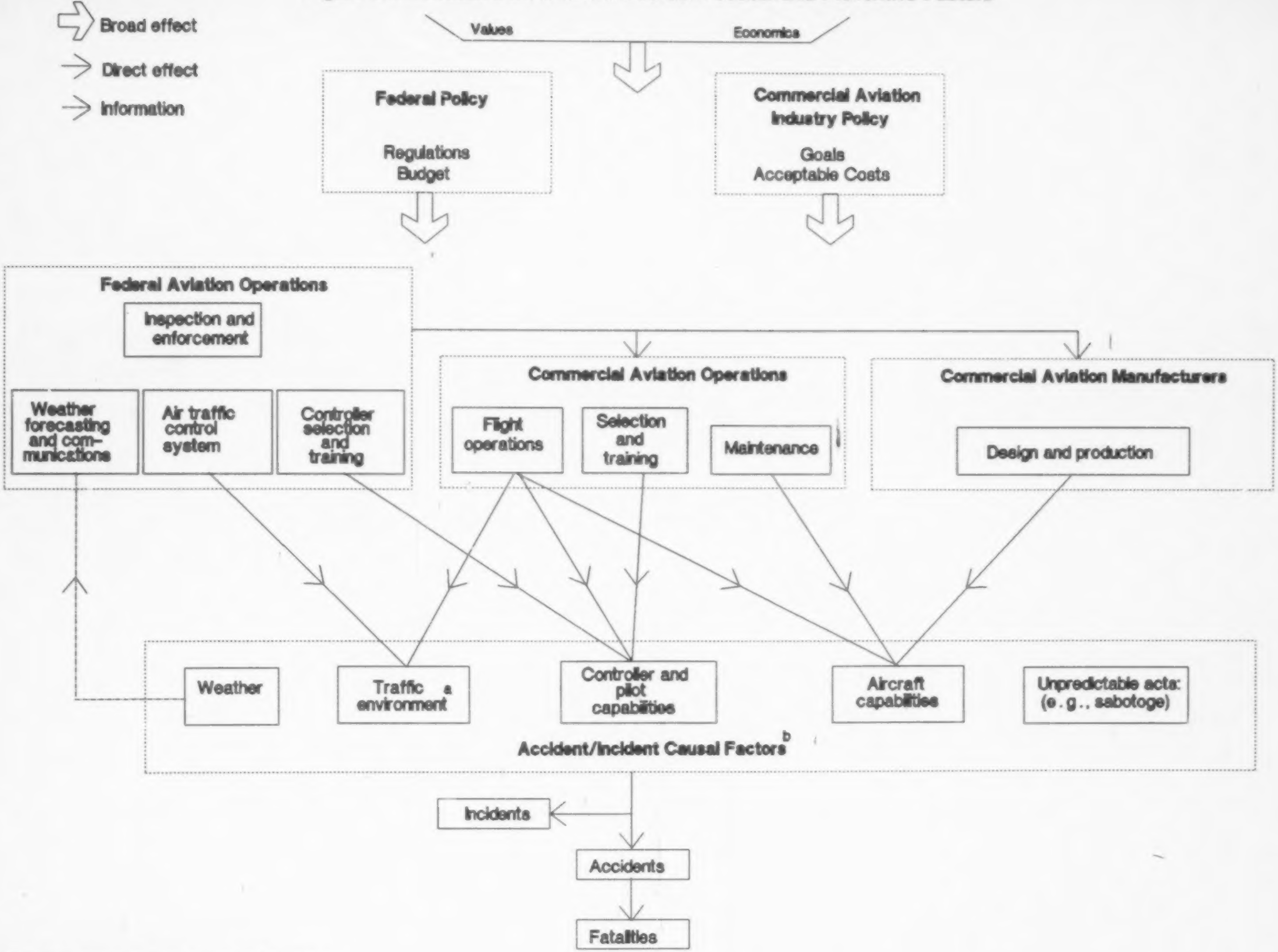
[4] On average, 50 percent of the passengers on board aircraft involved in fatal accidents perish. (See chs. 5 and 7.)

Figure 4-1.—Commercial Aviation Accident Causal and Preventive Factors


Broad effect
Direct effect
Information
Values
Economics
Federal Policy
Regulations
Budget
Commercial Aviation Industry Policy
Goals
Acceptable Costs
Federal Aviation Operations
Inspection and enforcement
Weather forecasting and communications
Air traffic control system
Controller selection and training
Commercial Aviation Operations
Flight operations
Selection and training
Maintenance
Commercial Aviation Manufacturers
Design and production
Weather
Traffic environment[a]
Controller and pilot capabilities
Aircraft capabilities
Unpredictable acts: (e.g., sabotoge)
Accident/Incident Causal Factors[b]
Incidents
Accidents
Fatalities

[a] Including general aviation, military, and other users.
[b] Causal factors influence each other.

SOURCE: Office of Technology Assessment.

Box 4-A.—Measures of Transportation Safety: Definitions

The context for these definitions is commercial aviation passenger transportation.

Accident: An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person (occupant or non-occupant) suffers a fatal or serious injury or the aircraft receives substantial damage. (49 CFR 830.2)

Fatal Injury: Any injury which results in death within 30 days of the accident.

Serious Injury: Any injury which requires hospitalization for more than 48 hours, results in a bone fracture, or involves internal organs or burns.

Substantial Damage: Damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component.

Incident: An occurrence other than an accident associated with the operation of an aircraft which affects or could affect the safety of operations. (49 CFR 830.2)

Level of Safety (or Risk): Fatality or injury rates. Only past levels of safety can be determined positively. Accident rates are closely associated with fatalities and injuries, and are acceptable measures of safety levels. Fatality, injury, and accident rates are benchmark safety indicators. Current and future safety levels must be estimated by other indicators or by extrapolating past trends.

Safety Factor: A procedure or event associated with fatalities, injuries, or accidents or their prevention.

Safety Indicator: A measurable safety factor.

Primary, Secondary, and Tertiary Safety Factors and Indicators: These safety factors and indicators describe the relative "closeness" between the measured safety factors and the fatality, injury, and accident rates. Theoretically, primary indicators would provide the best measures of changes in safety, followed by secondary and tertiary indicators. In practice, some tertiary indicators are more readily available and more accurate than primary indicators.

Primary Factors: These are most closely associated with fatalities, injuries, and accidents. Accident/incident causal factors, such as personnel and aircraft capabilities and the air traffic environment, are examples. Incidents and measurable primary factors are primary indicators.

Secondary Factors: These influence the primary factors. Airline operating, maintenance, personnel practices, along with Federal air traffic control management practices, are examples. Quantifiable measures of these factors, such as aircraft or employee utilization rates, are secondary indicators.

Tertiary Factors: These include Federal regulatory policy and individual airline corporate policy and capabilities that influence the secondary factors. An example of a tertiary indicator would be results of Federal air carrier inspections that quantify the extent of the carrier's regulatory compliance.

Exposure Data: Information that indicates the amount of opportunity for an event to occur. Cycles, distance, and time, for passengers or vehicles, are the principal exposure types. They are used in the denominator of rates, such as fatalities per passenger-departure and electrical system failures per aircraft-hour.

odology, because subjective influences and incomplete data affect analyses.

While most of the potential nonaccident indicators discussed in this section can be extracted from Federal and industry databases, in practice, they are not very useful for safety analysis. Much of the data come from voluntary reports submitted by pilots, mechanics, or controllers. Despite safety reporting requirements, ensuring compliance or consistency is difficult. Additionally, many of the databases were designed for administrative support functions, not as safety analysis tools.

Primary Safety Factors

Primary safety factors are those most closely correlated with accidents, and include incidents and accident causal factors. Theoretically, they are the best substitutes or alternatives to accident data.

Incidents

Incidents are events that can be defined loosely as "near-accidents."[5] Causal factors leading to accidents also lead to incidents, and all accidents begin as near accidents. The various combinations of possibly unsafe acts and conditions that occur each day usually end as incidents rather than accidents, and the larger number of incidents offers wider opportunities for safety trend analyses and for suggesting potential accident prevention measures. However, for an aviation incident to be widely known, it must be reported by at least one of the people involved. Yet, the definition of an incident is subject to the interpretation of the observer, and what appears to be an incident to one person may not to another. Thus, some information may be lost and measurement error may occur. Similar errors will result from incidents that are recognized, but not reported. Various sampling techniques can be employed for testing database consistency, and valid trend analyses are possible if errors in the data can be estimated. Incident types include:

Near Midair Collision (NMAC).—An incident associated with the operation of an aircraft in which the possibility of collision occurs as a result of proximity of less than 500 feet to another aircraft, or an official report is received from an aircrew member stating that a collision hazard existed between two or more aircraft.

Runway Incursion.—An occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing, or intending to land.

In-flight Fire.—A fire that occurs aboard an aircraft, whether or not damage occurs. Fire is extremely dangerous to aircraft and passengers because of the confined nature of cockpits and cabins, the amount and flammability of fuel, and the time involved in landing and evacuating an aircraft. Flight crews are required to report occurrences of in-flight fires to NTSB.

Flight-critical Equipment Failure.—"Flight-critical" is subject to various interpretations. Some examples are control system malfunctions and engine failures.

Accident Causal Factors

Aviation accident investigations attempt to determine and understand the causes leading to accidents, in the hope of preventing future mishaps. The findings can be grouped into five broad categories, as shown in the causal factors diagram. Few accidents (or incidents) result from a single, isolated cause—a combination of factors is usually involved. An examination of these causal factors points to possible indicators for monitoring safety levels. The five primary causal factor categories are discussed below.

Personnel Capabilities.—Human errors are factors in over two-thirds of commercial aviation accidents; they include lapses in attention, judgment, or perception and deficiencies in knowledge or motor skills. Such errors may be caused by vehicle, environmental, or health factors, including cockpit layout, workload, fatigue, or stress. Aviation personnel most subject to these errors include flight crewmembers, dispatchers, mechanics, and air traffic controllers.

In the operating environment, human errors are difficult to identify for a variety of reasons, including privacy and sensitivity; for example, possible measurements could include the results of periodic or continuous monitoring of operating personnel. However, human errors need to be understood to be prevented. Some indicators of personnel capabilities which are presently measured and used in either Federal or industry standards include employee duty hours, work hours, age, training, and experience levels.

Traffic Environment.—The structure of the airways and airports and the level and composition of air traffic heavily influence safety. Difficulties with facilities or traffic routing are usually discovered through incidents before an accident occurs. However, high traffic density puts continuous strains on many aspects of the air traffic control (ATC) system.

For a given air traffic infrastructure, increased traffic density most likely correlates with an increased risk of midair collisions. While the number of flight operations can be accurately counted or estimated, collisions occur too infrequently to correlate, and NMAC statistics are not as precise. Operational error, operational deviation, and pilot deviation[6] statistics are also potential air traffic safety indicators, but have similar consistency problems. Controller workload, the ratio of operations to controllers, might provide insight on air traffic safety if the type of ATC equipment being used and the nature of the traffic mix are considered.

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[5] The National Transportation Safety Board considers an incident to be "... an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations." 49 CFR 830.2 (Oct. 1, 1987).

Aircraft Capabilities.—The failure of an aircraft component is a factor in over 40 percent of jetliner accidents. Examples of components include engines, structural members, landing gear, control systems, and instruments. Mechanical failures can result from improper maintenance, design flaws, or operator error.

Replacement or repair trends, especially for flight-critical components, are possible indicators of safety, although the severity, along with the frequency of the component failure must be considered in quantifying risk. The Federal Aviation Administration (FAA), air carriers, and aircraft manufacturers maintain detailed databases of mechanical reliability data. Analysis and communication of observed trends prevent most problems from becoming critical. Other broad indicators include engine shutdown rates and unscheduled landings due to mechanical difficulties.

Weather.—Modern aircraft can operate in virtually all kinds of weather, but unpredicted severe conditions, such as wind shear or heavy icing, can prove deadly. Poor weather, compounded by mechanical difficulties or errors in judgment, provides a common scenario for aviation accidents. An understanding and timely monitoring of weather conditions is required for safe operation of aircraft, as shown in figure 4-1.

Unpredictable Events.—These are factors not included in the above categories, such as sabotage or terrorism. By definition, unpredictable or random events have no trends. Therefore, no unpredictable event indicators are possible except incidents and accidents, which will show levels of past risk.

Secondary and Tertiary Safety Factors: Industry Safety Posture

Commercial aviation safety is the dual responsibility of FAA and the airlines. Federal Aviation Regulations (FARs) set the framework for establishing commercial aviation operating practices. Under the current system, many practices tailored to individual carrier needs are allowable through programs approved by FAA Principal Inspectors and Flight Standards District Offices.

The commercial airline industry's operating practices—flight operations, maintenance, and training—are a dominant influence on the traffic environment, aircraft capabilities, and personnel capabilities causal categories discussed above.[7] These practices, along with the operation of the ATC system, are the secondary safety factors (see box 4-A).

The tertiary safety factors, furthest removed on the accident/incident causal chain, affect the industry operating practices listed above. Industry[8] philosophy and policy, which differ among airlines, dictate operating decisions. Federal regulatory policy in turn influences industry policy and operating practices. Qualitative assessments of the way operating practices affect safety performance are best made by independent inspectors using objective standards. In theory, FAA airline inspection programs are such assessments, although airline management and labor organizations receive relatively little attention in FARs.

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[6] William R. Hendricks, director, Aviation Safety, Federal Aviation Administration, attachment to letter to OTA, Dec. 18, 1987. The Federal Aviation Administration defines an "operational error" as ". . . an occurrence attributable to an element of the air traffic control system which results in less than applicable separation minima between two or more aircraft, or between an aircraft and terrain or obstacles and obstructions as required by FAA Handbook 7110.65 and supplemental instructions."

An "operational deviation" is ". . . an occurrence where applicable separation minima were maintained but loss in separation minima existed between an aircraft and protected airspace, an aircraft penetrated airspace that was delegated to another position of operation or another facility without prior approval, or an aircraft or controlled vehicle encroached upon a landing area that was delegated to another position of operation without prior approval."

A "pilot deviation" is ". . . the action of a pilot that results in the violation of a Federal Aviation Regulation or a North American Aerospace Defense Command (NORAD) Air Defense Identification Zone (ADIZ) tolerance."

[7] Manufacturers, through aircraft design and production, influence aircraft capabilities, and noncommercial flyers and Federal policy affect the air traffic environment. These are assumed to be beyond the direct control of the airlines.

[8] "Industry" includes airline management as well as labor unions.

Secondary Safety Indicators

FARs require the reporting of some data relevant to operating practices. For example, air carrier traffic, schedule, and financial information must be periodically submitted to the U.S. Department of Transportation (DOT). These data illustrate differences among carriers and over time, but as currently reported and reviewed, no correlation with safety has been established. Some examples of potential safety indicators are given below.

Flight Operations.—With the increased use of hub and spoke networks and the limits of the ATC system, airline flight crews and maintenance operations have felt new demands. While each airline will handle similar pressures differently, the trends in the indicators are important to understand. Some examples include: aircraft daily utilization (number of hours per day an aircraft is used); departures per aircraft per day; percent of fleet required for daily operations; and percent of flights into high density airspace.

Photo credit: Federal Aviation Administration

Consistent, centralized maintenance inspection data are vital for understanding airline safety.

Maintenance.—The aircraft capability indicators discussed previously are applicable measures of maintenance quality, though equipment design and manufacturing quality are important also. Unit maintenance costs can be used, but there are many reasons for variations among carriers and over time, such as productivity and technological changes.

Training.—Possible indicators include the number of hours of a type of instruction per applicable employee and the use of certain nonmandatory but valuable options, such as simulators, cockpit resource management, and wind shear training.

Tertiary Safety Indicators

FAA safety audits for regulatory compliance could indicate airline management attitude, organizational skill, and operational safety. While inspection data are subject to the personal biases of the individual inspectors, the use of objective inspection guidelines and standards, consistent and periodic audits, and varying inspection teams make inspection results valid measures of safety trends. Regulatory compliance data differ from previously discussed indicators in that the exposure parameters will no longer be miles, departures, or hours. Since FAA inspectors examine only a small percentage of an airline's records, aircraft, and operations, a measure of the quantity of inspection is needed in order to normalize the data used for analysis. For example, an inspection of 10 percent of the records of a large carrier would probably find more faults than a 10 percent examination of a small carrier. A measure of a carrier's exposure to inspection, such as the number of inspector man-hours performed or the number of records or operations examined, would be used as the denominator in the indicator ratio. The number of violations per inspection man-hour is an example of a regulatory compliance measure.

With appropriate guidelines, the quality of management practices could be measured by inspector assessment and ranking of certain aspects of airline operations. For example, two airlines may meet all Federal standards, but one may still be noticeably "safer" than the other. Objective standards are needed to permit consistent analyses across industry and time.

DATA RESOURCES

The Federal Government collects vast amounts of aviation data to support its responsibility for overseeing aviation safety, and automated systems are required for effective data processing. However, OTA research indicates that the analytical qualities of electronic data management systems and their data vary significantly among and within the Federal agencies dealing with aviation safety. The amount and caliber of safety data are significantly better for commercial aviation than for other transportation modes, but major barriers prevent effective use of the data. While frequently-cited accident and fatality statistics reflect past risk, a comprehensive program using Federal databases could identify and monitor changes in commercial aviation safety in a more timely manner. The central difficulties of such a program are:

- the consistency and availability of appropriate safety data,
- the accessibility and compatibility of various data systems, and
- an emphasis on administrative purposes in the design and use of the databases that makes analysis difficult.

These problems are not new. A 1980 General Accounting Office (GAO) report stated that FAA had not been effective or timely in developing systems to identify safety hazards.[9] The report futher explains that:

> . . . although FAA's hazard identification efforts have been numerous and varied, they have been hindered by insufficient information gathering, limited analysis that has not fully employed state of the art capabilities, and an inadequately planned and coordinated agency approach."[10]

A "blue-ribbon" committee of the National Research Council concurred with these findings and recommended that ". . . the FAA accelerate its development of an effective information-gathering and data system."[11]

Using the safety indicator theory developed earlier in this chapter, OTA reviewed a wide assortment of Federal aviation safety databases in an effort to document changes in commercial aviation safety during the past decade. A number of these databases contain ostensible safety indicator data (see table 4-2), but in practice, the nonaccident information has numerous shortcomings and is of limited use for safety trend analysis. An overview and assessment of each of the databases listed in table 4-2 are presented in this section, and uses and potential uses for these databases are given. (OTA analyses of these and other data are presented in chapter 5.)

Federal Safety Data Resources

DOT, which has regulatory responsibility for transportation safety, maintains the largest amount of aviation data. Within DOT, FAA, which monitors all aspects of aviation safety, and the Research and Special Programs Administration (RSPA) are responsible for the collection and management of safety and economic-related information. NTSB and the National Aeronautics and Space Administration (NASA) also keep specialized aviation safety data.

FAA

FAA is responsible for promoting aviation safety, achieving efficient use of airspace, operating an air traffic control system, and fostering air commerce. In support of these missions, FAA collects a wide range of aviation information and operates over 280 automated data systems.[12] Three organizations within FAA, the Associate Administrator for Aviation Standards, the Associate Administrator for Air Traffic, and the Office of Aviation Safety collect and manage most of the safety-related data.

Associate Administrator for Aviation Standards

Aviation Standards (AVS) personnel, working out of regional and field offices across the United States, collect and review large quantities of data

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[9] U.S. Congress, General Accounting Office, *How To Improve the Federal Aviation Administration's Ability To Deal With Safety Hazards*, GAO/RCED 80-66 (Washington, DC: Feb. 29, 1980), pp. 5-17.

[10] Ibid., p. 5.

[11] National Research Council, Assembly of Engineering, Committee on Federal Aviation Administration Airworthiness Certification Procedures, *Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft* (Washington, DC: National Academy of Sciences, 1980), p. 66.

[12] U.S. Department of Transportation, Federal Aviation Administration, *Information Resources Management Plan, Volume II: Systems Plan FY87-FY89* (Washington, DC: December 1986), p. 167.

Table 4-2.—Federal Aviation Safety Databases

Data type	Database	Federal agency	Earliest year[a]	Storage system for historical data
Accident/incident	Aviation Accident Data System	NTSB	1962	Digital DEC-10; published reports
Accident/incident	Accident Incident Data System	FAA	1978	Boeing Computer Services IBM 3084; Data General MV-15000
Incident	Aviation Safety Reporting System	NASA	1975	Battelle Columbus Laboratories: VAX integrated computer cluster
Incident	Near Midair Collision Database	FAA	1980	IBM/AT; published reports
Incident	Operational Error Database	FAA	1985	IBM/AT; published reports
Incident	Pilot Deviation Database	FAA	1985	IBM/AT; published reports
Mechanical reliability	Service Difficulty Reporting System	FAA	1978	Boeing Computer Services IBM 3084; Data General MV-15000; published data
	Air Operator Data System	FAA	1980	Boeing Computer Services IBM 3084; Data General MV-15000; published data
Traffic levels	Air Traffic Activity Database	FAA	Previous 18 months	Published reports
Operational practices	Air Operator Data System	FAA	1980	Data General MV-15000; published data
	Air Carrier Statistics Database	RSPA	1968	Digital DEC-10; published reports
Inspection results	Work Program Management System	FAA	1987	Data General MV-15000
Violation/enforcement actions	Enforcement Information System	FAA	1963	Boeing Computer Services IBM 3084; Data General MV-15000

KEY: NTSB = National Transportation Safety Board; FAA = Federal Aviation Administration; NASA = National Aeronautics and Space Administration; RSPA = Research and Special Programs Administration.

[a] Earliest year for data stored electronically.

SOURCE: Office of Technology Assessment, 1988.

as well as certificate aircraft, airmen, and airlines; oversee and enforce Federal Aviation Regulations; and investigate aircraft accidents and incidents. Many of these data are entered into the numerous databases maintained in Oklahoma City at the Mike Monroney Aeronautical Center and the Aviation Standards National Field Office (AVN).

The AVN and Aeronautical Center databases, used primarily to support administrative AVS tasks, reside on various computer hardware. Most of the data systems are hosted by the Aeronautical Center's IBM-3084 mainframe or AVN's Data General MV-15000 minicomputer, though some operate on the MV-8000's located at each regional office, the Burroughs B20 workstations distributed throughout FAA or the Transportation System Center's Digital DEC-10. Some of the systems, while required for the daily operation of AVS, are less important for analyzing system safety. Examples include databases containing airmen and airline certification records, medical records, aircraft registry and airworthiness information, and regulatory history. AVN does maintain four data systems which are used, or can be used, for safety analyses. These databases, containing information on aviation accidents and incidents, mechanical difficulties, regulation violations, and aircraft utilization and reliability, will be discussed in this section.

Some of the limitations of these independent and incompatible safety data systems have been recognized by FAA. The FAA Information Resources Management Program Office described the problems that arose from the lack of coordination during the development of the specialized data systems:

> Little consideration was given to the information requirements of other organizational elements within the agency. This approach has resulted in a number of fragmented data systems that contain nonstandardized data, having limited access, and do not satisfy the needs of all users. In addition, the

> data contained in these systems are not always current and lack the accuracy necessary to effectively meet the agency's program objectives.[13]

FAA is developing the Aviation Safety Analysis System (ASAS) to integrate and standardize current and future databases and maintain them on a central host computer linked via a telecommunication network to workstations located at all AVS facilities. An overview of ASAS is given later in this section.

The hardware and software compatibility problems limit the ease with which data are transferred between field personnel and AVN. With the exception of enforcement and inspection information, at present, data can be entered into the systems only in Oklahoma City. While this limits input errors (effectively, only one or two people enter data per database), timely responses are impossible. Though the field offices have access electronically to most of the systems, the databases are so intricate that data requests usually require processing by the limited number of AVN personnel.

Another option available to AVS personnel, as well as to any interested party, is a commercial timeshare network that presently contains three of the safety data systems. Operated by Boeing Computer Services, the system enables users to access the complete on-line FAA databases for accidents and incidents, service difficulty reports, and enforcement cases. Historical data, from as many as 5 previous calendar years, can be extracted in standard or custom-designed formats.

FAA Accident Incident Data System.—Accident data provide the key means of measuring aviation safety. An understanding of underlying accident causes and trends leads to preventive measures. Responsibility for investigating all civil aircraft accidents in the United States rests with NTSB,[14] though authority is delegated to DOT and FAA for certain accidents.[15] Both FAA and NTSB officials collect accident data, but NTSB alone determines probable causes. FAA is responsible for ensuring aviation safety, and investigates accidents primarily to assess whether corrective action is required in the aviation system. In January 1984, both agencies began using common forms, the NTSB series 6120, for the reporting of accident data. While efforts are underway to develop a joint NTSB/FAA accident database, both agencies currently maintain separate data systems. There is considerable, but not complete, overlap between the two systems. The NTSB Aviation Accident Data System contains all U.S. civil aircraft accidents and selected incidents, while the FAA Accident Incident Data System (AIDS) has fewer accident records, but substantially more incident data than the NTSB system.

AIDS contains general aviation and air carrier incidents dating from 1978, and general aviation accidents from 1973. In 1982, as a step toward the common NTSB/FAA accident database, air carrier accident information was introduced to the system. Though the NTSB database is considered the definitive source for aircraft accident data, AIDS is more accessible to FAA personnel on a daily basis. Copies of completed accident reports are forwarded from NTSB to AVN, where the data are entered into the Data General MV-15000 minicomputer.

While NTSB investigators also use the common series 6120 forms for reporting incidents,[16] AVS personnel use the less detailed FAA Form 8020-5. The completed FAA reports are sent to Oklahoma for processing and review, where contract personnel classify the incidents and assign probable cause factors. Other AVN employees encode and enter the incident information into the data system. However, the reports are not verified and no procedure is in place for ensuring consistent reporting from the field. OTA found substantial variation in the incident reporting rates among the FAA regions (see chapter 5).

AIDS data are available to FAA regional offices and headquarters via the commercial computer timeshare system operated by Boeing Computer Services or by printouts from AVN. OTA finds that while separate analyses of incident or accident data are possible, comparisons of accidents and incidents are difficult because FAA uses different terminology in classifying incidents than NTSB uses in accident/incident reports. OTA devised an algorithm for reorganizing FAA data into the NTSB format, and requested that AVN use it in extracting commercial aircraft accident and incident data. AVN provided little useful automated support. The algorithm required searches and combinations of AIDS data fields; OTA received unwieldy printouts of a portion of the data requested. Even if the missing information were available, extensive manual processing would be necessary to format the data.

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[13] U.S. Department of Transportation, Federal Aviation Administration, *Information Resource Management Plan, Volume I: Strategic Overview* (Washington, DC: December 1986), p. 22.

[14] 49 CFR 800.3 (Oct. 1, 1987).

[15] 49 CFR 800, app. (Oct. 1, 1987).

[16] By regulation, aircraft operators must notify the National Transportation Safety Board of five types of incidents (49 CFR 830.5), which may be investigated depending upon the circumstances and National Transportation Safety Board workload. This results in approximately 30 air carrier reports per year from the Board, compared with over 1,400 reports by Federal Aviation Administration investigators.

While NTSB and NASA provide detailed analyses of the accident and incident data they maintain, FAA examines air traffic incident data only. In 1984, the Safety Analysis Division of AVS was moved to the newly formed Office of Aviation Safety. Consequently, AVS does not have the resources to analyze air carrier incident or other data maintained in Oklahoma City. While sufficient information, such as causes and factors, is collected, it is not used in measuring and monitoring aviation system safety or to assist in setting regulations.

Enforcement Information System.—Theoretically, trends in the airline industry safety posture could be determined from the results of regulatory compliance audits performed by FAA inspectors. To accomplish this, the number and type of violations per carrier and some measure, such as inspector man-hours, of each airline's exposure to inspections would be needed. However, while all enforcement actions are tracked and recorded in the Enforcement Information System (EIS), little information is available on the number of inspections performed or the amount of time spent on them.[17]

EIS, which is managed by AVN on the MV-15000 minicomputer in Oklahoma City, was designed and is used primarily for administrative purposes. In support of AVS and General Counsel personnel, EIS tracks the complete history of each enforcement case and keeps copies of all documentation. Electronic records are available from 1963 to present. Because of the sensitivity of the data, only closed cases are available to the public.

EIS is the only AVN system that allows input directly from the field offices; the others require that the field personnel send paper copies of the data to Oklahoma City for processing by AVN personnel.

Service Difficulty Reporting System.—The mechanical reliability of aircraft and components is monitored by AVN analysts through the Service Difficulty Reporting System (SDRS). Reports, required by regulation,[18] are filed by air carriers, repair stations, manufacturers, FAA inspectors, and others concerning specific types of aircraft failures or malfunctions. These reports arrive at AVN in paper form where the data are encoded and entered into the MV-15000 minicomputer.

While containing data for over 10 years, SDRS is most useful for detecting short-term safety problems. The SDRS program automatically tracks trends in reports according to aircraft and component type. If the monthly or annual trend in reports exceed a pre-set value, then the system automatically alerts AVN analysts. An airworthiness directive, warning, or alert is issued to the public if, after review, the trend alert proves serious.

SDRS data are rarely used for long-term analyses. Due to the nature of the system, long-term adverse trends avoid detection since they have such shallow slopes they do not set off the alerting system. Also, since mechanical difficulties are often discovered during maintenance inspections, the frequency and depth of these inspections, along with the willingness of the airlines to file reports, affect the SDRS database.

Air Operator Data System.—AVS personnel must frequently refer to information about air carriers and other commercial operators and the structure of their organizations, fleets, and facilities. While such information is available in fragments from many sources within DOT, the Air Operator Data System (AIROPS) attempts to consolidate the vital data available from within FAA. Of interest for safety analysis are data involving aircraft operations, such as utilization and engine reliability.

Unlike other AVS data gathering efforts discussed (accident/incident, enforcement, service difficulties), there is no regulatory requirement for air carrier reporting or FAA collection of "air operator" data as such.[19] Air carrier inspectors, though, follow general guidelines for collecting the data monthly. They send air operator data to Oklahoma City by mail for processing. While AVN employees ensure accurate transcription of data, there are no procedures in effect for ensuring accuracy at the source. The National Air Transportation Inspection (NATI) Program, which relied on AIROPS for many of its activities, discovered many errors in the data. The NATI report concluded that the Air Operator Data System is ". . . in need of corrections and enhancements."[20] Data have been collected and published in the monthly Air Carrier Aircraft Utilization and Propulsion Reliability Reports since the 1960s, though due to contractor problems, no reports were released between January and August 1987.[21]

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[17] U.S. Congress, General Accounting Office, *Aviation Safety: Needed Improvements in FAA's Airline Inspection Program are Underway*, GAO/RCED 87-62 (Washington, DC: May 1987), pp. 24-38.

[18] 14 CFR 121.703 and 14 CFR 135.415 (Jan. 1, 1987).

Air operator data provide the opportunity for analyzing certain air carrier operating practices, by individual company or industry wide. When used in conjunction with other system information, daily utilization data give one view of the amount of schedule pressure placed on aircraft fleets. Engine reliability data, the basis for overwater flight certification, indicate the final product of equipment design and airline maintenance and operating procedures.

Work Program Management Subsystem.—FAA's struggles to modernize its air carrier inspection program are documented in a recent GAO report.[22] FAA senior management and safety analysts knew little about the inspections being performed during the post-deregulation period. The only attempt at using inspection results for analysis followed the NATI Program in 1984. The NATI Task Force, comprised of former FAA inspectors, reviewed the NATI reports and found that over 20 percent of the carriers analyzed had a "less than desirable compliance posture,"[23] and that FAA inspector surveillance and enforcement needed improvement.[24] The NATI Program also identified FAA problems in collecting and managing inspection data.[25]

Even before NATI occurred, FAA was planning an automated system for tracking the inspection program. However, the Work Program Management Subsystem (WPMS), implemented in October 1984, has been plagued by problems. The microcomputers, on which the inspection data are entered, have insufficient capacity for the system requirements. Additionally, there are not enough of the computers to go around. Moreover, FAA installed inadequate software in the system, limiting the type and extent of the inspection data available for analysis.

Changed in October 1986, the current software provided some usable data in fiscal year 1987. FAA's Western Pacific Region has successfully utilized WPMS for inspection efforts, though it still cannot access the central computer in Oklahoma City. WPMS has aided FAA's geographic inspection concept by allowing field inspectors throughout the United States to send inspection results directly to the carrier's respective principal inspector.

Though designed primarily as a tool for managing the FAA inspection program, WPMS can potentially be used for safety analysis. WPMS data, centrally stored at AVN, enable a compilation of inspection results and a measure of exposure (inspector-hours).

Using the Data Systems for Analysis

OTA found few presentations, let alone analyses, of the safety data contained in the AVS data systems. Moreover, the systems are difficult to use for safety analyses for two fundamental reasons. First, AVN exercises little quality control of data collection and reporting, because it has neither the manpower nor the imperative to do so. Furthermore, no plans are underway for ensuring that FAA field personnel or airlines collect and report accurate data.

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[19] Air carriers must report organizational, operational, and financial data to the Research and Special Programs Administration's Office of Aviation Information Management (and previously to the Civil Aeronautics Board) as required by 14 CFR 241 and 14 CFR 298. Certain engine problems must be submitted via mechanical reliability reports as stated in 14 CFR 121.703 and 14 CFR 135.415.

[20] U.S. Department of Transportation, Federal Aviation Administration, "National Air Transportation Inspection Program," report for the Secretary, Mar. 4-June 5, 1984, p. 36.

[21] The data were consolidated and released in special reports in fall 1987.

[22] General Accounting Office, op. cit., footnote 17.

[23] U.S. Department of Transportation, Federal Aviation Administration, "Memorandum on Evaluation of National Air Transportation Inspection Program Inspection Reports," April 1985, p. 37.

[24] Ibid, p. 41.

[25] Federal Aviation Administration, op. cit., footnote 20, p. 23.

Second, extracting useful data from an established database requires not only an understanding of the safety problem to be analyzed, but knowledge of the limitations of the computer systems and the intricacies of the data fields. These AVN data systems were not designed as analytical tools, and AVN personnel are not trained analysts. FAA plans to address some aspects of this problem by implementing the Aviation Safety Analysis System (ASAS), which, as envisioned, will consolidate and standardize new and existing safety databases. In contrast to the present system, FAA personnel without extensive training in computer programming will have access to a wide range of safety data via desktop workstations.

ASAS was conceived in 1979 to build upon the general office automation program for regional and field offices then in development at FAA. New office equipment, proposed as part of the automation program, was to have sufficient processing and network capabilities for an integrated safety data system. The numerous compatibility and communication difficulties created by the data systems then in use (for the most part, still in use) at FAA were to be addressed by ASAS. An ASAS Program Office was established in 1982 and a long-term phased development plan was proposed. The initial phase will integrate and standardize current data systems. Subsequent phases will implement and develop new databases.

Photo credit: Federal Aviation Administration

FAA inspectors and safety analysts need ready access to complete and accurate data.

The types of ASAS databases fall into four categories: 1) airworthiness data; 2) regulatory data; 3) operational data; and 4) organizational information. Airworthiness data are mainly historical information on aircraft, such as mandatory modifications specified by FAA. Regulatory data consist of background information, such as Notices of Proposed Rulemaking, legal opinions, and previous regulations. Data describing the aviation environment are included in the operational category. These databases track airmen, aircraft, and operators along with accidents, incidents, mechanical reliability reports, and enforcement actions. The work management subsystems to monitor AVS tasks, such as airline inspections, fall into the category of organizational information.

ASAS will alter many of the tasks currently performed by AVS personnel. Data will be entered and validated where it is collected and generated, at the field office level. This increase in employee exposure to automated systems implies a need for substantial training and for user-friendly equipment and software. The problems with WPMS, discussed earlier, illustrate the need for proper training and technology. It is also proposed that field personnel will be able to perform their own data analyses using information from several databases through analytical software packages.

Associate Administrator for Air Traffic

In managing the National Airspace System (NAS), Air Traffic (AAT) personnel control traffic, operate facilities, and develop procedures and standards for airways, airspace, and flight operations. On a daily basis, information is collected and reviewed concerning air traffic levels, NAS status, system errors, controller errors, pilot deviations, and delays, although most of the data are entered into automated systems only after reaching specific offices within FAA headquarters. Other offices, regions, or field facilities within AAT do not have ready access to many of these systems.[26] However, Office of Air Traffic Evaluations and Analysis specialists monitor every report on operational errors, NMACs, and pilot deviations and communicate findings to the field facilities.[27]

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[26] U.S. Department of Transportation, Federal Aviation Administration, *Information Resource Management Plan, Volume I: Strategic Overview* (Washington, DC: October 1985), p. 14.

While AAT tracks and analyzes air traffic safety data, it does not manage the data systems dealing with incidents or system-wide operational information of interest to this study. The Office of Aviation Safety (discussed in the next section), handles the incident data while the air traffic activity data are processed by the FAA Office of Management Systems. The Office of Air Traffic Evaluations and Analysis is developing its own data system, the Operational Error Reporting System, to receive and track operational error reports in a timely fashion. The system has been on-line, linking a number of regional offices with headquarters, since June 1987.

Air Traffic Activity Database.—An essential exposure measure for air safety analysis is the level of traffic. One parameter, departures, is the best exposure reference for general safety comparisons. While departure data are available for specific carriers from Civil Aeronautics Board records and RSPA, system-wide traffic data, including departures, are available from the Air Traffic Activity Database.

Air traffic control personnel keep track of the daily activity at ATC facilities. Monthly summaries of various operations, including the number of takeoffs and landings at airports with control towers and the number of aircraft handled by radar control facilities, are submitted to the Office of Management Systems in FAA headquarters. There the data are encoded for entry into the Boeing Computer Services System, where they are processed and cross-checked. Due to the large volume of monthly data, the Boeing system is not used for analysis or storage, but as a tool for preparing summary reports. Annual Air Traffic Activity Reports are published and are available to the public.

Facility, region, or system-total data are available, with tables categorizing information by aircraft operator (air carrier, air taxi, general aviation, and military). This study used historical tower activity data to illustrate the growth of hubs and as the exposure reference for air traffic incidents. The number of aircraft handled by en route radar controllers is an alternate measure of traffic trends.

Office of Aviation Safety

Reporting directly to the FAA Administrator, the Office of Aviation Safety conducts accident investigations, safety analyses, and special programs. In this role, it monitors or manages several databases. The Office of Aviation Safety operates the National Airspace Incident Monitoring System, an automated system containing NMAC, operational error, and pilot deviation databases. FAA maintains contact with the NASA-administered, but FAA-funded, Aviation Safety Reporting System through the the Safety Analysis Division within the Office of Aviation Safety.

Near Midair Collision Database.—FAA learns about NMACs primarily from pilot reports, though air traffic controllers, passengers, and ground observers also serve as notifiers. In each case, a preliminary report is filed and must be investigated by FAA within 90 days.

Although the AVS Accident Incident Data System tracks NMACs, they are not included in its database. All incident reports involving air traffic operations, including NMACs, end up in the Office of Aviation Safety. There, the data are encoded and entered into an IBM/AT personal computer system located at FAA headquarters. NMAC information from 1980 to the present is available in the system. FAA has had widely publicized difficulties with its NMAC data, and instituted a monitoring procedure in 1985 to ensure proper handling of NMAC reports. An interagency task group consisting of FAA, NASA, and the Department of Defense was formed in 1986 to review existing NMAC data and recommend ways to reduce the midair collision threat. The recommendations cover equipment, airspace structure, data reporting, and pilot training. Additionally, the Office of Aviation Safety is presently conducting a number of NMAC studies.

Operational Error Database.—The loss of legal flight separation around an aircraft which is attributed to the ATC system is an operational error (see footnote 6). For example, during en route operations, controllers are required to keep aircraft apart by 5 miles horizontally and 1,000 feet vertically for flights below 29,000 feet and 2,000 feet vertically for flights above. Operational deviations, generally less serious than operational errors, do not involve loss of separation between two aircraft, but result from an aircraft passing too close to a restricted airspace or landing area.

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[27] B. Keith Potts, associate administrator, Air Traffic, Federal Aviation Administration, personnel communication, Dec. 22, 1987.

From 1983 to 1985, FAA instituted two changes. First, the enroute ATC computers were reconfigured with the Operational Error Detection Program which automatically records and reports any loss of proper separation for aircraft in the system. Second, the responsibility for maintaining an operational error report database was shifted to the Office of Aviation Safety. Preliminary reports of operational errors and deviations are filed from the ATC facility within 48 hours after the event's occurrence. All reported operational errors and deviations are investigated, and depending on the outcome, a final report is submitted. Personnel from the Office of Aviation Safety encode and enter preliminary and final report data into the IBM/AT.

Pilot Deviation Database.—An ATC facility that observes a pilot deviation is responsible for reporting it to the appropriate Flight Standards office for investigation. Prior to 1985, incidents involving pilot deviations were entered into AVN's Accident Incident Data System, though they were not specifically categorized as pilot deviations. Presently, the results of pilot deviation investigations are sent directly to the Office of Aviation Safety where the data are entered into an IBM PC. The Office of Aviation Safety is responsible for tracking and reporting trends in pilot deviations, and published its first statistical report of pilot deviations in October 1987.[28] Similar to the operational error data, pilot deviation information stored electronically extend back only to 1985.

NTSB, in a special investigation of runway incursions, found that as with operational errors, many pilot deviations are not being formally reported but are resolved informally at the ATC facility involved.[29] Additionally, prior to 1985, reports reaching Flight Standards were investigated primarily to determine violation and enforcement actions against the pilot involved, not for safety analysis.[30] The number of pilot deviation reports processed by the Office of Aviation Safety is increasing every year (over 2,500 in 1986), though how much of that growth should be attributed to changing reporting practices is open to question.

National Transportation Safety Board

NTSB is responsible for investigating all aircraft accidents and certain incidents, determining their probable causes, and making recommendations to FAA. It keeps an extensive database of accident information in an automated system and publishes accident reports and the results of other special investigations.

Aviation Accident Data System.—Since its inception in 1967, NTSB has kept records of civil aircraft accidents.[31] The current automated database, the Aviation Accident Data System, contains information on aviation accidents and incidents. Primarily designed for administrative purposes, the system does have analytical capabilities. NTSB publishes Annual Reviews of Aircraft Accident Data and occasional Special Studies, which are supported by statistical analyses accomplished with the data system.

The NTSB Aviation Accident Data System contains information on every known civil aviation accident[32] in the United States. Selected incidents, as listed in 49 CFR 830.5, are also included in the database. The system encompasses data from 1962 to the present, though changes were made in reporting methods during this period. A single format was used until 1982, when the procedure and report form was revised. The documentation was again changed in 1983, when NTSB accident investigators began submitting data in the format that was eventually adopted as NTSB series 6120.4. The data from the reports are entered into the computer, along with the findings of probable cause and contributing factors. Computer searches are possible with any data block or group of blocks as selection criteria.

Differences in data formats impose some restrictions on possible computer-assisted analyses. For example, in 1982, NTSB changed its method of classifying accidents. Accidents are now categorized by the first "occurrence" in the sequence of events that led to the accident. Earlier, groupings were made by the accident "type." NTSB has developed a matrix for comparing occurrences and types. For broad safety studies, the effect of the format changes is small. While the collection of data has essentially remained the same, the latter format allows a more detailed analysis of accident circumstances.[33]

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[28] U.S. Department of Transportation, Federal Aviation Administration, *Selected Statistics Concerning Reported Pilot Deviations (1985-1986)* (Washington, DC: October 1987).

[29] National Transportation Safety Board, *Special Investigation Report—Runway Incursions at Controlled Airports in the United States,* NTSB/SIR-86/01 (Washington, DC: May 6, 1986), p. 8.

[30] Ibid, p. 8.

[31] From 1940 to 1967, the Civil Aeronautics Board investigated accidents.

[32] Accidents involving only military or public-use aircraft are not usually investigated by the National Transportation Safety Board.

NASA

NASA, which provides and supports aviation research and development, administers the confidential and voluntary Aviation Safety Reporting System (ASRS). ASRS is designed to encourage reports by pilots and air traffic controllers concerning errors and operational problems in the aviation system, by guaranteeing anonymity and immunity from prosecution for all reporters. ASRS data can provide an alternate Federal insight into the nature and trends of aviation incidents.

NASA Aviation Safety Reporting System.—ASRS is a joint effort by FAA, NASA, and the Battelle Memorial Institute to provide a voluntary reporting system where pilots, controllers, and others can submit accounts of safety-related aviation incidents. The system is funded mainly by FAA, administered by NASA, and maintained by Battelle. Reports are sent to the ASRS office at NASA Ames Research Center and the data are analyzed and entered into a computer by employees of Battelle. The database is maintained at Battelle Columbus Laboratories in Ohio.

Prior to the establishment of ASRS in 1976, attempts at providing voluntary incident reporting programs met with little success. Potential reporters feared liability and disciplinary consequences. Even after FAA introduced its Aviation Safety Reporting Program (ASRP), which offered limited immunity and anonymity to participants, few reports were submitted. The aviation community feared that FAA, responsible for setting and enforcing regulations, would misuse the data. FAA acknowledged these concerns and transferred control of ASRP to a neutral third party, NASA. A Memorandum of Agreement was executed between FAA and NASA in August 1975, establishing ASRS. The Agreement provided for a limited waiver of disciplinary action, confidentiality of reporting sources, and an Advisory Committee comprised of representatives of the aviation community. ASRS became operational on April 15, 1976.[34]

Voluntary reports, useful for understanding the nature of incidents, are somewhat deficient in indicating prevalence or frequency. Therefore, ASRS was planned as an "analytical rather than a descriptive system."[35] The ASRS report form (NASA Form ARC 277) was designed to gather the maximum amount of information without discouraging the reporter. Structured information blocks and key words are provided, not only to guide the reporter, but to aid subsequent data retrieval and research. Narrative descriptions are encouraged. Space is provided for the reporter's name, address, and telephone number. This permits NASA to acknowledge the report's receipt by return mail, and also allows the Battelle analyst to contact the reporter for followup data. Information that identifies the reporter is deleted before being entered into the computer.

Under the guidance of NASA, Battelle receives the incident reports, processes and analyzes the data, and publishes reports of the findings. Human factors in aviation safety, a continuing concern at the NASA Ames Research Center, were a major consideration in ASRS development. The data analysts, primarily experts in aircraft operations and air traffic control, provide insight into the nature of the human error or other underlying factors in the incidents. Although the reports are encoded in detail, the complete narrative text of each report is retained for later re-evaluation.

Because ASRS is voluntary and reporters are deidentified, a concerted effort among a number of individuals can distort the database. For example, air traffic controllers at certain facilities increased their reporting of incidents associated with a display system that they wanted upgraded. This reporting campaign ended with the air traffic controllers strike in August 1981.[36]

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[33] National Transportation Safety Board, *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, Calendar Year 1982*, NTSB/ARC-86/01 (Washington, DC: n.d.), p. 1.

[34] William D. Reynard, Aviation Safety Reporting System, in U.S. Congress, House Committee on Science and Technology, Subcommittee on Investigations and Oversight, *Aircraft Safety Technologies* (Washington, DC: U.S. Government Printing Office, Nov. 23, 1985), p. 29.

[35] Charles E. Billings, M.D., the National Aeronautics and Space Administration Ames Research Center, "Human Factors in Aircraft Incidents: Results of a 7-Year Study," *Aviation, Space, and Environmental Medicine*, October 1984, p. 961.

RSPA

The Office of Aviation Information Management of RSPA assumed the former Civil Aeronautics Board's responsibility for collecting data on airline operations, traffic, and finances beginning in 1985. Airlines submit data periodically in accordance with 14 CFR Parts 217, 234, 241, 291, and 298. While these data do not directly indicate safety, they do provide measures of exposure such as departures, hours, and miles. However, the airline categories for exposure data reporting do not correspond to the operating categories used by NTSB for classifying accidents, resulting in some gaps and inaccuracies in statistics. Financial statistics also have potential uses in analyses, since many in industry and government believe that economics influence safety to some degree.

Air Carrier Statistics Database.—Part 217 Reporting Data Pertaining to Civil Aircraft Charters performed by U.S. and Foreign Air Carriers (14 CFR 217) requires U.S. and foreign air carriers to file traffic data on any civilian international charter flight flown to or from the United States in large aircraft (over 60 seats or 24,000 pounds of payload). The information reported quarterly shows the charter passengers or tons of cargo flown between the origin and the destination point of the charter. The information is reported by aircraft type by month.

Part 234 Airline Service Quality Reports (14 CFR 234) requires 14 certificated U.S. air carriers (a carrier with more than 1 percent of total domestic scheduled passenger revenues) to file monthly flight performance information for every domestic nonstop scheduled passenger operation to or from the 27 largest U.S. airports (airports with more than 1 percent of domestic scheduled passenger enplanements). Carriers are voluntarily reporting data for each domestic scheduled flight instead of limiting their reporting to the 27 airports. For the origin airport of each nonstop segment, the carrier reports published departure times versus actual departure times; for the destination airport, the published arrival times versus the actual arrival times are reported. This information is reported by date and day. Flights delayed because of mechanical reasons, as defined by FAA, are not reported.

Part 241 Uniform System of Accounts and Reports for Large Certificated Air Carriers (14 CFR 241) prescribes the accounting and reporting regulations for large U.S. certificated air carriers (Section 401 certificate). A large carrier is defined as a carrier operating aircraft which are designed to accommodate more than 60 seats or a cargo payload of more than 18,000 pounds. All large carriers, according to the level of their operations, as measured by annual operating revenues, are placed into one of four groups: Group I Small ($10 million and under), Group II Large ($10,000,001 to $75 million), Group III ($75,000,001 to $200 million) and Group IV (over $200 million). The amount and detail of reporting increases with carrier size. Data are submitted on individual schedules of the DOT Form 41 Report or by electronic media. In general, carriers report exposure data such as aircraft departures, hours, miles, and passenger enplanements in total and by aircraft types. A broad range of financial data including categories of revenues and expenses are also reported, with those related to operations being indexed by aircraft type.

Part 291 Domestic Cargo Transportation (14 CFR 291) prescribes the reporting required of carriers providing domestic all-cargo operations exclusively under Section 418 certificates. These carriers are required to file Form 291-A, a one page annual report, which contains seven profit and loss items, and seven traffic and capacity items. The data are not reported by aircraft type.

Part 298 Exemptions for Air Taxi Operations (14 CFR 298) prescribes the reporting for small certificated air carriers (Section 401 certificate) and commuter air carriers. Both classes of carriers operate aircraft which are designed for 60 seats or fewer or for 18,000 pounds of cargo capacity or less. A commuter air carrier is defined as a special classification of air taxi operator that provides passenger service consisting of at least five roundtrips per week between two or more points. Commuters report only traffic exposure data totals with no indexing by aircraft type. Small certificated air carriers submit the same information as commuters plus revenue and expense data. The direct expense data and three operational items (block hours, departures, and gallons of fuel issued) are indexed by aircraft type on small certificated air carrier reports. Air taxi operators which are not commuters have no reporting requirements.

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[36] William D. Reynard, chief, Aviation Safety Reporting System, personal communciation, Feb. 23, 1988.

Various reports including electronic submissions are sent monthly, quarterly, semiannually, and annually to the Office of Aviation Information Management, where the data are entered into the Amdahl computer located in the DOT headquarters building in Washington, DC. Most of these data are published or loaded on magnetic tapes and are available to the general public by subscription.

CONCLUSIONS AND OPTIONS

No single measurement or statistic provides a complete picture of commercial aviation safety. While accident and fatality statistics are the best measures of long-term past risk in commercial aviation, they are of limited value over short periods of time and are not suitable monitors of short-term effects of policy decisions. For example, the consequences of recent rulings requiring collision avoidance systems on commercial transports and transponders on many general aviation aircraft may not be apparent in the accident data for 5 years or more.

Nonaccident safety data, while not substitutes for accident and fatality data, are valuable supplements. If properly collected and maintained, nonaccident data can help identify and estimate the magnitude of safety problems and permit the monitoring of safety programs. **OTA concludes that nonaccident data must be used in short-term safety analyses.**

FAA has made great strides in recent years in collecting and analyzing air traffic incident data. Indeed, OTA found FAA's air traffic data to be the most useful nonaccident indicators of system safety. However, since the air traffic system is so safe, only a fraction of the commercial aviation accidents and fatalities are caused by the air traffic environment. Consequently, additional nonaccident data are required for tracking changes in commercial aviation safety. **OTA finds that FAA programs to identify and monitor changes in the commercial aviation safety system need upgrading.**

With the exception of airline inspection records, sufficient data for better monitoring and assessing of commercial aviation safety are collected by or are available to Federal aviation authorities. However, FAA quality control programs need improvement to ensure accurate and consistent data collection and reporting. For example, the FAA computer center in Oklahoma City, which maintains most of the air carrier-specific information, does not verify incoming data. Furthermore, most of the databases are designed primarily for recordkeeping; this constrains, but does not prohibit, analysis.

OTA found the analytical capabilities of both the personnel and the data system at NTSB to be valuable resources. NTSB could readily provide published reports or customized computer printouts; much of the accident data used in this study was supplied by NTSB. **OTA found that while both NTSB and FAA maintain accident/incident air carrier specific databases and are under tight staff restrictions, the close coordination among NTSB data system managers, analysts, and field personnel enables NTSB to use its data system effectively for analysis in contrast to FAA's system in Oklahoma City.**

The FAA electronic systems required for processing the vast amount of data collected are adequate storage media, but their flexibility and utility for safety analysis vary widely. Experienced safety analysts, the eventual system users, took part in the design of the NASA ASRS and remain involved in the processing and encoding of data. **OTA found ASRS data, along with FAA air traffic information, to be the most valuable incident data on commercial aviation that it reviewed. ASRS stands as an excellent example of how to develop and manage an aviation safety data system. OTA found that the close working relationship among data**

managers and analysts allows ASRS to be used for a wide range of accident prevention efforts. The system could serve as a useful model for Aviation Standards data systems, which were configured to accept data from report forms poorly designed for computer input. Additionally, the FAA computer center staff, while knowledgeable about and competent in using the systems, are not trained analysts. To compound problems, FAA management structure reflects the fragmented nature of the FAA data systems. Three separate FAA organizations have safety data responsibilities, and databases, data terminology, and automated systems are often incompatible within and among these organizations.

The few FAA studies that use nonaccident data appropriately have come primarily from the Office of Aviation Safety. Recent studies by this office focused on ATC system difficulties, such as near midair collisions, air traffic controller errors, and pilot deviations. On the other hand, the Office of Aviation Safety has had little success in using the AVS data systems and their air carrier information. For example, the Office of Aviation Safety prepares the *Annual Report on the Effect of the Airline Deregulation Act on the Level of Air Safety*, which does not present or appropriately analyze available nonaccident statistics. **The effect of airline operating or management practices, or changes in those practices, on commercial aviation safety are rarely addressed in FAA studies.** Air carrier-specific information systems, such as the Work Program Management Subsystem and the Air Operator Data System, are essential tools for properly trained field office personnel in support of AVS's commercial aviation oversight role. OTA finds that improved access to these databases is needed at regional and field offices, a key consideration for future FAA information systems and enhancements currently being developed.

The advent of airline deregulation raised concerns that economic pressures could force airline managements to cut back on safety practices. The Office of Flight Standards, responsible for periodically inspecting all airlines to ensure regulatory compliance, is the logical choice for resolving this issue, but needs to collect and retain the necessary data. **Consistent, centralized records on the number, extent, and results of air carrier inspections are vital to ensuring the efficacy of FAA's safety function.**

Four data areas (all used to varying degrees throughout FAA) could provide warning signals for directing FAA attention, and with further refinement, could allow quantified estimates of changes in risk. They include:

- aircraft mechanical reliability, including unscheduled landings due to mechanical problems;
- airline operating practices, including aircraft scheduling and flightcrew work and duty shifts;
- inspection results, including quality assessments of airline practices and violation rates; and
- financial condition of airlines, and how that relates to any of the other safety indicators.

Airlines themselves keep crucial safety information and FAA could benefit from working more closely with airline data. For example, many air carriers maintain large internal databases that could be used to validate FAA databases. However, ensuring the confidentiality of the air carrier data is critical. **FAA could encourage improved air carrier reporting of sensitive safety data, such as incidents, by guaranteeing that no penalties will result from reported information and could consider making nonreporting a violation.** Additionally, access to airline computer systems, such as maintenance management systems,[37] could enhance FAA's monitoring capabilities.

While airlines share safety information through industry and government sponsored workshops, committees, and forums, no formal, centralized industry process is in place for collecting and evaluating these data. The airlines, as a group, might consider developing a data system to serve as a cooperative industry clearinghouse for safety-related maintenance, training, and operating information. The system could be established independently or in conjuction with FAA, and ideally would tap the potential of the airlines' extensive automated information systems.

OTA concludes that all current FAA data systems could benefit from a thorough, coordinated, agency-wide review, although enough shortcomings are known now to effect significant improvements in the system. Data managers, analysts, and field personnel should be involved collectively in all new data system development projects.

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[37] One major airline recently provided the Federal Aviation Administration direct access to its computerized maintenance records.

Furthermore, OTA finds that an agency-wide, system safety management approach for data responsibility is needed, and that immediate coordination of Aviation Standards, Air Traffic, and the Aviation Safety Office efforts could bring major benefits providing support of policy development and planning, and permitting more focused allocation of agency resources. The current fragmented approach creates inconsistencies, nonstandardization, poor quality control, incompatible electronic systems, and insufficient data and data analyses. In the long term, FAA could establish a consistent monitoring and analysis program to refine the selection of safety indicators and the procedures for collecting and processing information. Safety management, including data managing, is an iterative process.

Chapter 5

Safety Data Analysis—What Do We Know

Photo credit: Federal Aviation Administration

An FAA inspector observes an airline captain's instrument flying technique.

CONTENTS

Page
Accident Data ... 93
  Accidents and Fatalities ... 93
  Accident Causes and Types ... 95
Nonaccident Safety Data ... 98
Incident Data ... 98
  Air Traffic Incidents ... 99
  General Incidents ... 102
Accident/Incident Causal Factors ... 103
  Aircraft Capabilities ... 103
  Personnel Capabilities ... 105
  Traffic Environment ... 105
Management Practices ... 105
  Maintenance ... 106
  Operations ... 108
  Regional/Commuter Airline Operations ... 109
  Employee Selection and Training ... 110
Management Policies ... 111
Conclusions and Policy Options ... 112

Figures

Figure *Page*
5-1. Passenger Fatality Rates for Part 121 Scheduled Airlines ... 93
5-2. Airline Accidents Initiated by Aircraft Equipment Failure ... 96
5-3. Part 121 Accident Broad Causes and Factors ... 96
5-4. Air Carrier Near Midair Collisions (1975-87) ... 100
5-5. Operations Per Controller at Towers and Centers ... 102
5-6. Basic In-flight Shutdown Rate, B727/JT8D Engines ... 104
5-7. Average Flight Equipment Maintenance Expense for B727-200 Fleet ... 107

Tables

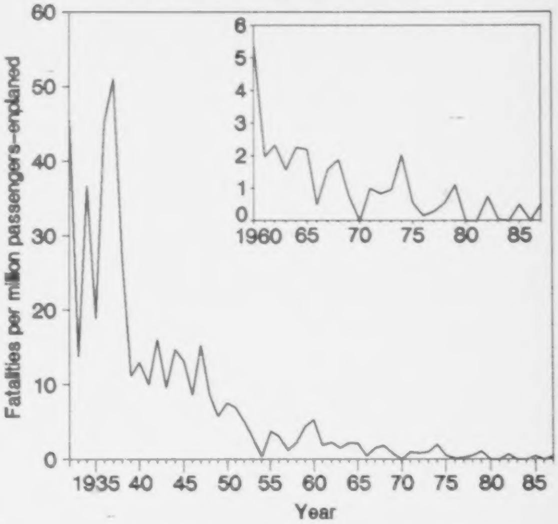
Table *Page*
5-1. Commercial Aviation Accident and Fatality Totals, 1975-1987 ... 94
5-2. Commercial Aviation Accident and Fataltity Rates ... 94
5-3. Accident Categories ... 97
5-4. Part 121 Fatal Accidents, 1975-86 ... 97
5-5. Part 121 Total Accidents, 1982-1985 ... 98
5-6. Commercial Aircraft Midair Collisions ... 99
5-7. Qualifications of New-Hire Commercial Flight Crews ... 110

Chapter 5

Safety Data Analysis—What Do We Know

Data attest to the safety of commercial aviation; statistics show that over the years the risk of injury or death has steadily declined for airline passengers (see figure 5-1). However, increased traffic congestion and new and different operating patterns have placed unprecedented demands on the aviation system. Measuring recent changes in passenger risk is difficult because accidents are infrequent and data on other safety factors are not systematically collected or maintained (see chapter 4). OTA searched government and industry databases for potential safety indicators, and conducted case studies and surveys of airline management, pilots, and mechanics. The results of these efforts are presented in this chapter. Tasked with assessing commercial aviation safety, OTA focused primarily on Part 121[1] airlines, which carry about 95 percent of the passengers and account for 99 percent of the passenger-miles. However, Part 135 commuter airlines are responsible for the safety of a significant number of people—over 18 million passengers in 1986—and their operations are discussed as well.

Figure 5-1.—Passenger Fatality Rates for Part 121 Scheduled Airlines



SOURCE: Office of Technology Assessment based on data compiled from the Civil Aeronautics Board, Federal Aviation Administration, and National Transportation Safety Board.

ACCIDENT DATA

Accidents and Fatalities

Airline passenger risk is not gauged solely by numbers of fatalities; rather, passenger injury or fatality rates and the rate at which flights end in accidents or crashes are considered the best indicators of past risk. Statistical comparisons for commercial aviation are skewed by differences in aircraft size and in flight distances. For example, since the mid-1970s, Part 121 airline operators have had the fewest fatal accidents; however, because each plane carries many passengers, these operators have had the most passenger fatalities in commercial operations (see table 5-1). To complicate analysis further, over 70 percent of jetliner accidents occur during takeoff, initial climb, final approach, or landing, but these represent only 6 percent of the flight time and even less of the mileage.[2] Therefore, departure information for aircraft and passengers is necessary to estimate risk, and other exposure data do not permit appropriate comparison among the aviation categories. (See chapter 4 for further discussion.)

Although accident data are considered generally accurate and complete, exposure data quality varies with the aviation segment. While most scheduled Part 121 carriers must report extensive traffic data under U.S. Department of Transportation (DOT) requirements, smaller charter, commuter, and air

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[1] Airline operations with airplanes having more than 30 seats or payload capacity greater than 7,500 pounds are certificated under 14 CFR 121. Airlines flying smaller airplanes are governed by 14 CFR 135, or if they choose, the more demanding 14 CFR 121.

[2] Boeing Commercial Airplane Co., *Statistical Summary of Commercial Jet Aircraft Accidents: Worldwide Operations 1959-86* (Seattle, WA: April 1987).

Table 5-1.—Commercial Aviation Accident and Fatality Totals, 1975-87

	Part 121 (scheduled)	Part 121 (nonscheduled)	Part 135 (scheduled)	Part 135 (nonscheduled)
Accidents	269	50	446	1,918
Fatal accidents	37	11	109	435
Fatalities	1,393	668	431	1,086

SOURCE: Office of Technology Assessment based on National Transportation Safety Board January 1988 data.

taxi airlines need report little or none. DOT publishes estimates of all Part 121 and scheduled Part 135 aircraft departures and of all Part 121 passengers carried; these data are used in this chapter. However, OTA had to derive commuter passenger statistics from data collected by the Regional Airline Association (RAA), and estimated air taxi passenger and departure figures from information supplied by the National Air Transportation Association. Due to inherent inaccuracies in these data, the estimates have limited utility for trend analyses, but they are valid approximations of exposure magnitude.

Aircraft departures and passenger enplanements[3] are incorporated into the accident and fatality rates shown in table 5-2. These data show no significant

Table 5-2.—Commercial Aviation Accident and Fatality Rates

Year	Part 121 (scheduled)	Part 121 (nonscheduled)	Part 135[a] (scheduled)	Part 135[b] (nonscheduled)
Accidents per million departures:				
75-77	4.8	53	27	58
78-80	3.7	39	27	54
81-83	4.1	18	12	55
84-86	2.8	22	8	53
87	4.3	23	14	38
75-87	3.8	30	17	54
Fatal accidents per million departures:				
75-77	0.48	10.6	6.3	11
78-80	0.57	6.5	6.5	13
81-83	0.72	2.6	2.6	13
84-86	0.34	8.0	2.1	11
87	0.43	4.6	4.1	12
75-87	0.51	6.5	4.1	12
Fatalities per million passengers-enplaned:[c]				
75-77	0.34	24.2	3.4	14
78-80	0.56	0.2	4.4	13
81-83	0.26	0.1	1.5	11
84-86	0.17	14.7	1.6	9
87	0.41	0.1	2.8	10
75-87	0.33	9.1	2.6	12

[a] Scheduled Part 135 passenger counts estimated by OTA based on Regional Airline Association data.

[b] Nonscheduled Part 135 passenger and departure data estimated by OTA based on National Air Transportation Association and other air taxi data.

[c] OTA calculations based on National Transportation Safety Board and Federal Aviation Administration data. All 1987 rates based on estimated passenger-enplanement data.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988, unless otherwise noted.

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[3] Passenger *departures* would be a better choice here, but the data are not available. Passenger *enplanements*, or the number of people who board flights, are recorded. Passenger departures equal passenger enplanements on nonstop flights, but are greater on multistop flights.

Fatalities per passenger-carried is one statistical method to normalize the fatality rates among the various industry segments, and offers a sound comparison tool. Fatalities per aircraft-departure, -hour, or -mile would be skewed by aircraft size and range. Since each fatality is not an independent event, these statistics must be used with caution. The three types of risk measurements presented should be considered together.

increase in past passenger risk since the enactment of the Airline Deregulation Act. Indeed, 1984 to 1986 was the safest 3-year period for the large scheduled airlines, and commuter lines improved their safety record substantially, although the downward accident trend faltered in 1987. The inaccuracy of the exposure data limits conclusions regarding safety trends for nonscheduled airlines; however, it appears that air taxi safety remained unchanged.

The relative infrequency of Part 121 charter operations and accidents makes trend analyses for that part of commercial aviation very difficult. Accident rates for scheduled Part 121 and 135 airlines in 1987 were higher than in recent years,[4] although fatality and accident statistical trends for a single year must be viewed with caution. Since commercial aviation accidents are relatively rare, a single crash of a large jet can skew the statistics.

Large aircraft fatal accidents usually result in either few fatalities or few survivors. From 1975 to 1986, only 17 Part 121 accidents with 10 or more fatalities occurred, and of those accidents, 7 accounted for over 70 percent of the fatalities.

Industry segments have distinctly different accident rates. For example, scheduled Part 121 airlines have significantly better records than other types of air transportation. In contrast, nonscheduled 121 airlines provide less than 3 percent of the Part 121 departures and passengers, but account for 23 percent of the fatal accidents and 32 percent of the fatalities.

Commuter airlines have accident and fatality rates 3 to 10 times above those of the large scheduled airlines. These disparate levels of safety often reflect differences in safety regulations, equipment, and operating environments. For example, commuters may have less advanced technologies or lower training levels than major airlines because they have fewer aircraft in their fleets and fewer passengers per flight to distribute the costs involved. The largest commuter airlines have the best safety records; indeed the 20 largest Part 135 commuters (and Part 121 regionals) have safety records similar to those of jet carriers.[5] Aircraft type and airport characteristics have little influence on the safety record.[6]

Accident Causes and Types

The primary purpose of accident investigations is to determine the probable causes of transportation accidents and to recommend preventive measures. Because most accidents involve a complex congruence of multiple events and causes, aviation accidents do not lend themselves to simple classification or categorizing by type or cause. Moreover, accidents of the same type often require several different preventive measures, although single solutions can sometimes reduce the occurrence rate of a wide range of accidents. For example, ground proximity warning devices reduced markedly the rate of controlled flight into terrain accidents for jetliners (see chapter 7).

The National Transportation Safety Board (NTSB) currently classifies accidents by a variety of methods, such as causes and factors, sequence of events, and phase of operation. Determining up to five distinct occurrences in the chain of events leading to an accident, NTSB categorizes the accident by the first occurrence. While events such as aircraft component failures and encounters with weather are prominent in first occurrences, human errors are harder to trace from the data.[7]

OTA completed a trend analysis of aircraft component failure as a first occurrence in airline accidents (see figure 5-2). The analysis showed no significant change in the rate for Part 121 carriers and noticeable improvements by the Part 135 commuters during the past decade. Therefore, any recent changes in Part 121 airline maintenance practices appear not to have affected aircraft mechanical reliability in a way that results in more accidents. Data on other common first occurrences, such as encounters with weather or collisions with objects or terrain, cover too broad a range of accident circumstances to provide meaningful trends.

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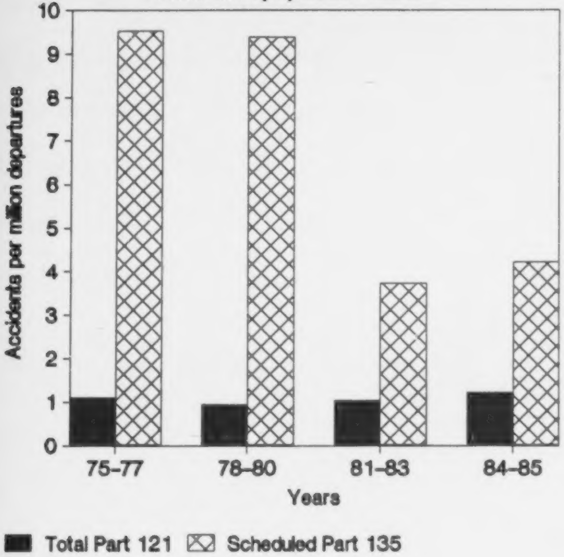
[4] National Transportation Safety Board data released Jan. 13, 1988.

[5] Clinton V. Oster, Jr. and C. Kurt Zorn, "Airline Deregulation, Commuter Safety, and Regional Air Transportation," *Growth and Change*, vol. 14, July 1983, pp. 3-11.

[6] Ibid.

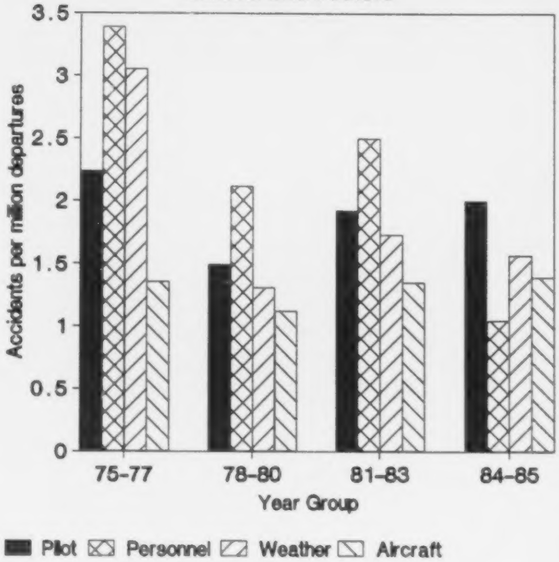
[7] Stan Smith, accident data chief, National Transportation Safety Board, personal communication, May 15, 1987.

Figure 5-2.—Airline Accidents Initiated by Aircraft Equipment Failure



SOURCE: Office of Technology Assessment from National Transportation Safety Board findings of the "first occurrence" in the sequence of events leading to the accidents, 1975-1985.

Figure 5-3.—Part 121 Accident Broad Causes and Factors



SOURCE: Office of Technology Assessment based on National Transportation Safety Board data.

Accident causal data usually imply corrective actions, but since accidents frequently have multiple causes, developing causal categories is difficult. In most cases, each cause is independent of the others, and if one did not exist, the accident might not have occurred. However, analyzing the multiple causes of accidents does highlight the relative prevalence and trends of certain factors. Figure 5-3 shows that while weather- and personnel-related (nonpilot) causal rates for Part 121 accidents diminished prior to deregulation, pilot error and aircraft-related causal rates have changed little.

Boeing, the Flight Safety Foundation, and others have categorized accidents by primary cause. This method gives a clear cross section of accident events and allows accident classification. However, determining which of the multiple causes is the most important is a subjective process. One analysis of major accidents involving large jet transports worldwide found that only 28 percent had a single probable cause,[8] and OTA found that at least 40 percent of Part 121 fatal accidents could not be adequately accounted for by single causes.

Each of these analysis types thus has shortcomings for understanding the complexity of individual accidents. As an alternate method, OTA identified the two most significant sequential causal events in each accident.[9] After reviewing NTSB Part 121 accident briefs, OTA classified all fatal Part 121 accidents from 1975 to 1986 and total Part 121 accidents from 1982 to 1985 according to the classification scheme shown in table 5-3.[10] The relative

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[8] Richard L. Sears, "A New Look at Accident Contributors and the Implications of Operational and Training Procedures," *Influence of Training, Operational and Maintenance Practices on Flight Safety*, Proceedings of the Flight Safety Foundation's 38th Annual International Air Safety Seminar (Arlington, VA: Flight Safety Foundation, Nov. 4-7, 1985), pp. 29-51.

[9] For a variation of this method, see Clinton V. Oster, Jr. and C. Kurt Zorn, Transportation Research Center, Indiana University, "Improving Military Charter Safety," unpubished manuscript, November 1987.

[10] Other causal categories are possible, but were not necessary for Part 121 accidents OTA reviewed.

Table 5-3.—Accident Categories

- I. Collisions
  - A. Controlled flight
    - 1. Pilot error, then flight path deviation
    - 2. Pilot error, then aircraft component failure
    - 3. Personnel error, then flight path deviation
    - 4. Personnel error, then aircraft component failure
    - 5. Aircraft component failure
    - 6. Miscellaneous[a]
  - B. Uncontrolled flight
    - 1. Pilot error, then aircraft component failure
    - 2. Pilot error, then encounter with weather
    - 3. Pilot error, then flight path deviation
    - 4. Personnel error, then aircraft component failure
    - 5. Personnel error, then weather
    - 6. Aircraft component failure, then pilot error
    - 7. Encounter with weather, then aircraft component failure
    - 8. Aircraft component failure
    - 9. Encounter with weather
    - 10. Miscellaneous[a]
- II. No collision
  - A. Controlled flight
    - 1. Pilot error
    - 2. Personnel error
    - 3. Aircraft component failure
    - 4. Miscellaneous

[a] OTA classified midair collisions under the miscellaneous category. While a midair could fit possibly into any of the collision categories above, midairs are distinct enough to warrant a separate classification, but are too rare to call for a special category.

SOURCE: Office of Technology Assessment, 1988.

prevalence of accidents according to causal factors is presented in tables 5-4 and 5-5—approximately 60 percent of the fatal accidents by scheduled passenger carriers are initiated by human error, and human error is a causal factor in over 70 percent of these accidents. Aircraft component failure, severe weather, and miscellaneous causes initiated the remaining accidents.

However, when nonfatal accidents are included, the influence of mechanical failure doubles; it is the enabling cause in over 30 percent of all accidents and is involved in almost 50 percent.[11] Additionally, noncollision accidents, which are rarely fatal, result primarily from aircraft component failures. Two fatal noncollision accidents occurred between 1975 and 1986, as compared to 9 nonfatal noncollision accidents between 1982 and 1985; all of these accidents involved aircraft component failures.

Table 5-4.—Part 121 Fatal Accidents, 1975-86

	Scheduled passenger	Scheduled cargo	Nonscheduled passenger	Nonscheduled cargo	Total	Total[a] (by percent)
Initiating causal factor:						
Pilot	10	1	1	3	15	43
Personnel	3[b]	1[c]	1[d]	0	5	14
Aircraft	4	1	1	3	9	26
Weather	3	0	0	0	3	9
Miscellaneous	2[e]	0	0	1[f]	3	9
All causal factors:[g]						
Pilot	13	2	2	3	20	57
Personnel	3	1	1	0	5	14
Aircraft	6	1	1	4	12	34
Weather	8	0	1	0	9	26
Miscellaneous	2	0	0	1	3	9
Total accidents	22	3	3	7	35	

NOTE: Accidents involving weather turbulence, sabotage, or nonoperational events, such as ramp activities, are not included.

[a] Initiating causal factors may not total 100 percent due to rounding. For all causal factors, numbers do not total 100 percent because most accidents involve multiple causes.

[b] Two accidents involving air traffic control personnel and one involving maintenance personnel.

[c] Accident involved air traffic control personnel.

[d] Ground collision caused by other pilot.

[e] Two midair collisions, including Aeromexico DC-9/PA 28-181 over Cerritos, CA, Aug. 31, 1986.

[f] In-flight collision with parachutist.

[g] All causal factors includes up to two significant causes in the sequence of events leading to the accident.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988.

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[11] The failure of an aircraft component, such as landing gear, may cause substantial damage to the aircraft but not subject the passengers to harm. See "accident" definition, box 4-A, ch. 4.

Table 5-5.—Part 121 Total Accidents, 1982-85

	Scheduled passenger	Scheduled cargo	Nonscheduled passenger	Nonscheduled cargo	Total	Total[a] (by percent)
Initiating causal factor:						
Pilot	14	5	1	3	23	46
Personnel	3[b]	0	0	1[c]	4	8
Aircraft	12	1	2	3	18	36
Weather	2	0	0	0	2	4
Miscellaneous	3[d]	0	0	0	3	6
All causal factors:[e]						
Pilot	16	6	2	3	27	54
Personnel	3	0	0	1	4	8
Aircraft	16	1	2	4	23	46
Weather	8	2	1	0	11	22
Miscellaneous	3	0	0	0	3	6
Total accidents	34	6	3	7	50	

NOTE: Accidents involving weather turbulence, sabotage, or nonoperational events are not included.

[a] For all causal factors, numbers do not total 100 percent.

[b] Two accidents involving air traffic control personnel and one involving maintenance personnel.

[c] Accident involved maintenance personnel.

[d] Two collisions with birds and one collision while taxiing.

[e] All causal factors includes up to two significant causes in the sequence of events leading to the accident.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988.

NONACCIDENT SAFETY DATA

Since aviation accidents are so infrequent, trends observed over 1 or 2 years of accident data may not be meaningful or indicate actual changes in risk. Despite the long-term improvement in aviation safety, recent concern over near midair collisions (NMACs) and airline operations suggests an interest in more timely information on changes in aviation safety. The Federal Aviation Administration (FAA) currently collects many types of nonaccident safety data, such as information on air carrier operations and incidents, but data quality and system limitations prevent analysis of all but a few years of air traffic safety data.

Database validity is the key problem in nonaccident safety data analyses. While aircraft accidents leave permanent evidence, many nonaccident safety events (such as NMACs) are transitory, and some go unrecognized, while others are inaccurately observed. Moreover, even when an event is observed and recognized correctly, it may not be reported for a number of reasons, including misunderstanding of the reporting process, apathy, and fear of repercussions. Current FAA practices present the reporter with many personal risks, including prosecution for Federal Aviation Regulations (FARs) violations, employer sanctions, and time lost for the administrative process.[12]

Nonaccident data analyses have multiple purposes —while isolated reports of safety events can identify the existence of a problem, data must be collected broadly and consistently to estimate reliably the extent of the problem. Moreover, complete and accurate data are required for understanding the causes of problems and for developing countermeasures. Data system management is the final hurdle for nonaccident data utility. Incoming reports must be properly handled and consistently organized, and the resulting databases must be accessible to analysts.

INCIDENT DATA

Every accident begins as an incident, and incidents are reported much more frequently than accidents to National Aeronautics and Space Administration (NASA), NTSB, and FAA databases. Thus aviation incidents, or "near accidents," are good substitutes for sparse accident data. Additionally, more information, especially regarding human performance causal factors, is often available from them for safety investigators, since incidents do not result in fatalities or serious damage.

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[12] For these reasons, the Federal Aviation Administration grants immunity and guarantees anonymity to reporters who use the Aviation Safety Reporting System, which is administered by the National Aeronautics and Space Administration.

However, incident data are difficult to collect reliably, primarily because of the imprecise definition for aviation incidents. NTSB considers an "incident" to be ". . . an occurrence other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operations."[13] For specific incident types—an in-flight fire, for example—better criteria are used. If collected and analyzed separately, these specifics offer valuable information on safety.

As the ratio of incidents to accidents varies by accident/incident category, trends in total incidents can be misleading. For example, a rise in a widespread, but low-risk incident type and a decrease in an infrequent, but high-risk incident type results in an increase in the total incident rate, although overall risk may be reduced. Analyses by specific accident/incident type avoids this confusion.

Air Traffic Incidents

Air traffic incidents, such as NMACs, runway incursions, and operational errors, reflect aspects of air traffic system[14] safety. For the most part, analyses of these data address aircraft classes, such as air carrier or general aviation (GA), and airspace categories—Terminal Control Areas, for example. Air traffic incidents are defined more clearly than general incidents and are reported primarily by air traffic controllers and pilots.

Near Midair Collisions

An in-flight collision involving a passenger transport is among the most feared of aviation accidents. While such collisions are rare events (see table 5-6), they account for roughly 10 percent of fatalities. Statistics indicate a very low risk with no discernible trends in these accidents, but annual increases in the reported number of NMACs have created concern.

Table 5-6.—Commercial Aircraft Midair Collisions

	Part 121 (total)	Part 135 (scheduled)	Part 135 (nonscheduled)
1975-1977	0	2	4
1978-1980	1	0	9
1981-1983	0	2	8
1984-1986	0[a]	1	2
1987	0	1	2

[a] A midair collision between an Aeromexico DC-9 and a private PA 28-181 occurred over Cerritos, CA on Aug. 31, 1986.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988.

FAA and NASA collect data on NMACs independently, but both agencies rely on voluntary reports. FAA investigates each report and can impose penalties if regulations were violated. In contrast, NASA maintains the anonymity of the reporter and FAA guarantees immunity from potential penalties that could result from the event. FAA has cited its own mismanagement of NMAC report paperwork, as well as changes in public perception and awareness, as reasons for not using the FAA NMAC database for trend analysis. FAA corrected its report processing problems in 1985,[15] and claims that recent increases in NMAC rates more closely reflect reality.[16]

OTA finds that substantial evidence points to analytically valid subsets of NMAC data. FAA recovered many missing 1983 and 1984 NMAC reports, and FAA and NASA databases show similar trends from 1981 to the present; moreover, NASA data were not subject to management problems during this period. However, this does not preclude changes in pilot (the primary reporters of NMACs) perception from influencing both sets of data.

Air carrier pilots are a relatively homogeneous group who are very aware of incident-reporting procedures and may thus be more likely than GA pilots to report an observed NMAC. Moreover, air carrier pilots fly primarily under instrument flight rules (IFR) and, if involved in an NMAC, would be in communication with air traffic control (ATC). For reporting purposes, aircraft involved in NMACs are grouped into three categories: air carrier (Part 121 or 135 operators), GA, and military. Air carrier and GA aircraft are involved in over 95 percent of the reported NMACs.[17]

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[13] 49 CFR 830.2 (Oct. 1, 1987).

[14] The "air traffic system" includes all flight operations, not only those under air traffic control.

[15] Burt Solomon, "FAA Runs Into Some Heavy Turbulence in Aviation's Worst Year for Fatalities," *National Journal*, Oct. 12, 1986, pp. 2313-2316.

[16] Donald Engen, administrator, Federal Aviation Administration, "Aviation Safety (Near Midair Collisions and Runway Incursions)," testimony before U.S. Congress, House Committee on Public Works and Transportation, Subcommittee on Investigations and Oversight, Apr. 9, 1987, p. 66.

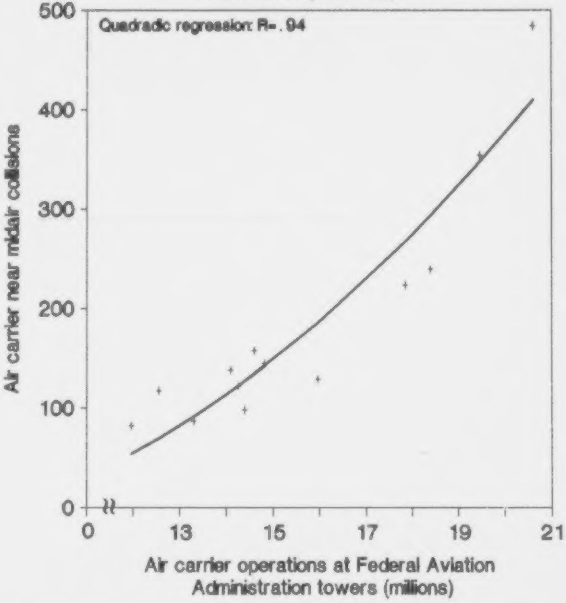
The FAA Office of Aviation Safety found that less than 20 percent of air carrier/GA and military/GA incidents are reported by the GA operators involved.[18] In a comparative analysis of FAA and NASA NMAC reports, OTA found that about 18 percent of the air carrier-involved NMAC reports in the FAA database show up in the NASA data, as contrasted to less than 10 percent of all FAA NMAC reports. Air carrier NMAC data are more consistent than the other subsets of the data, including the total.

Theoretically, the NMAC rate (and the actual collision rate) is proportional to traffic density raised to some power.[19] Since traffic density data are not readily available, OTA used aircraft operations (takeoffs and landings) at towered airports as a substitute. OTA found that the annual number of air carrier operations and the annual number of reported air carrier-involved NMACs fit a nonlinear model well, as shown in figure 5-4. Despite the implication that increases in air carrier traffic will result in higher numbers of air carrier NMACs, accident data do not bear out a correlation between increasing frequency of reported NMACs and increasing risk of collision. The sparseness of the collision data prohibit determining valid trends; we simply cannot tell with current information.[20]

Runway Incursions

A collision between two airliners on a runway can be just as devastating as a collision in the air; the greatest loss of life in aviation resulted from such an accident involving two B-747s in Tenerife in 1977. Near collisions on the ground raise many of the same concerns as near collisions in the air.

Figure 5-4.—Air Carrier Near Midair Collisions (1975-87)



SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

Currently, runway incursions (see definition in chapter 4) as well as other ground incidents caused by an air traffic controller's actions are reported as "operational errors," and when the pilot is at fault, the event is reported as a "pilot deviation." Additionally, some runway incursion reports end up in the NMAC database.[21] Because FAA has not systematically collected data or published analyses on runway incursions and does not maintain a separate runway incursion database (although it plans to establish one),[22] information on runway incursions must be extracted from these other databases, which have been maintained in their current form only since 1985.

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[17] U.S. Department of Transportation, Federal Aviation Administration, "Selected Statistics Concerning Pilot Reported Near Mid-Air Collisions (1983-85)," June 1986, p. A2-1.

[18] Ibid, p. 8

[19] The near midair collision risk is proportional to the number of potential conflict pairs of aircraft (approximately the number squared) per area for a two dimensional, random flight path model. See Walton Graham, Questek, Inc., "Technology Requirements as Derived From Accident Rate Analysis," AIAA-80-0918 (Washington, DC: American Institute of Aeronautics and Astronautics, May 1980).

[20] The Federal Aviation Administration's Office of Aviation Safety's Safety Analysis Division has several studies underway of near midair collisions by airport and airspace location.

[21] Brian Poole, Federal Aviation Administration, Office of Aviation Safety, personal communication, Jan. 21, 1988.

[22] Ken Chin, Federal Aviation Administration, Office of Aviation Safety, personal communication, Nov. 3, 1987.

While most runway incursions are probably observed by the controllers or pilots involved, an NTSB special investigation found that the data are not complete and are difficult to use effectively.[23] NTSB uncovered several runway incursions, classified as operational errors or pilot deviations, that controllers did not formally report.[24] FAA's Air Traffic Evaluations and Analysis Division reviews all operational error reports and has established a task group to study surface incidents, and the Office of Aviation Safety tracks statistics regarding surface deviations by pilots.

NASA collects runway "transgression" data through Aviation Safety Reporting System (ASRS) reports. Runway transgressions are defined as any erroneous occupation of a runway at a controlled airport by an aircraft or other controlled vehicle. Traffic growth resulting in more reported NMACs may have a similar influence on surface problems; indeed, runway transgressions show similar trends to those of NASA and FAA NMAC reports. However, while transgressions have been increasing, the conflicts (or near collisions) resulting from them have not increased since 1984, according to ASRS data.

Operational Errors and Deviations

Since 1985, FAA has maintained an automated database of operational errors and operational deviations. Simply phrased, these incidents are occurrences attributed to ATC operations that result in improper separation between an aircraft and another aircraft, terrain, or obstacles (operational error) or infringement upon protected airspace by an aircraft (operational deviation). (See chapter 4 for complete definitions.)

The quality of operational error/deviation data varies by subset. Operational error/deviation data are categorized by type of ATC facilities—terminals[25] and en route centers. For centers, operational errors and deviations are tracked automatically by the Operational Error Detection Program, while error information at terminals comes primarily from reports initiated by the personnel directly involved in the incident. (At en route centers, 57 percent of errors and deviations are reported by automatic systems, as compared to 10 percent at terminals. Not surprisingly, the reported error/deviation rate at centers was nearly four times greater than at terminals, yet terminals handle about twice the number of aircraft.)[26] Consequently, many aspects of operational errors/deviations can be more accurately analyzed when the data are grouped by ATC facility.

Without the aid of significant technological developments (see chapter 7), air traffic controllers faced increasing workloads throughout the past decade. The average number of flight operations handled by each controller[27] in recent years is higher than for any period except the one immediately following the controller's strike in August 1981,[28] as illustrated in figure 5-5. (Actual workloads vary considerably at individual centers and terminals.)[29]

The FAA Office of Aviation Safety has analyzed in detail the 1985 and 1986 data. The precise relationship between growing traffic levels and error rates is not clear. Overall traffic and controller workload have increased since 1985, and reported controller errors declined from 1985 to 1986, and then increased at half the rate of the traffic growth in 1987. FAA investigated error/deviation rates for a given year at facilities with varying traffic loads. For center data (the most reliable), there are no well-defined relationships between error/deviation rates and the average annual workload per controller or the number of operations at the regional or individual facility level.[30] For terminal data, no correlation was found at the individual facility level, though some was observed on a regional basis. Higher error/deviation rates occurred for terminals in regions with the lower controller workloads.[31]

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[23] National Transportation Safety Board, *Special Investigation Report—Runway Incursions at Controlled Airports in the United States*, NTSB/SIR-86/01 (Washington, DC: May 6, 1986).

[24] Ibid.

[25] Terminals are the facilities, such as towers and approach controls, that provide air traffic control services at airports.

[26] Ibid, p. 3-7.

[27] For this analysis, a "controller" is a Federal Aviation Administration employee who directs air traffic. Full performance level controllers, qualified on all air traffic control positions in a tower or center, and developmental controllers, qualified on at least one position, are included.

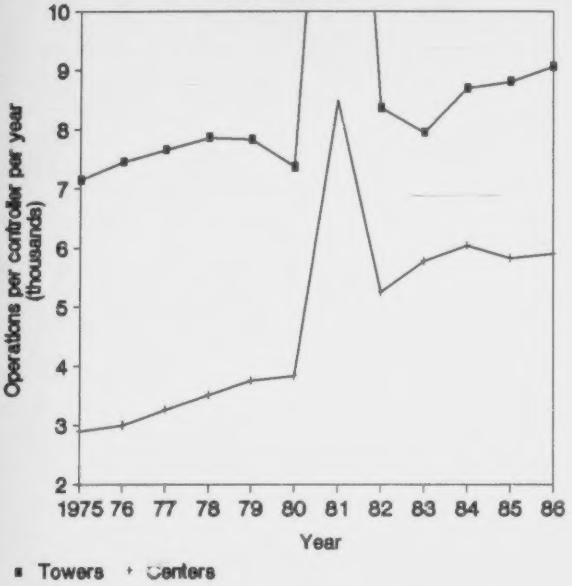
[28] For the latter half of 1981 and much of 1982, some military air traffic controllers were assigned to centers and towers.

[29] U.S. Department of Transportation, Federal Aviation Administration, *Profile of Operational Errors and Deviations in the U.S. Air Traffic System, Calendar Year 1985* (Washington, DC: May 1986), pp. 3-55 and 3-58.

[30] Ibid, p. 3-53.

[31] Ibid, p. 3-53.

Figure 5-5.—Operations Per Controller at Towers and Centers



NOTE: 1981 rates are distorted due to the walkout and subsequent dismissal of controllers.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

The causal categories for operational errors and deviations are human error, equipment problem, and faulty procedure;[32] human error was involved 98 percent of the time. FAA examined controller experience as a factor in the human error-caused incidents, and found that center controllers with 6 to 8 years of full performance level experience had by far the highest error/deviation rate in 1985, more than seven times greater than other controllers. (Similar data are not available for terminals.)[33] FAA has not conducted a similar analysis of 1986 or 1987 data.

In summary, the only conclusion that can be drawn from current operational error/deviation data is that no drastic deterioration in ATC safety has occurred. Consistent data over a longer timeframe and additional analysis could shed light on the correlation among incident rates, traffic levels, and controller workload.

General Incidents

Although FAA has improved its collection and analyses of ATC incidents since 1985, the agency gives scant attention to other air carrier and GA incidents. Aviation Standards manages the reporting process for these incidents, and maintains them in its Accident/Incident Data System (AIDS). However, AIDS has limited analytical capabilities, and the data, as currently processed, have little value as accident data surrogates.

AIDS was established primarily for administrative purposes; FAA cannot ensure easily that airlines report incidents accurately and consistently, and does not make certain that its investigators process the information properly. OTA compared the distribution of incident reports by FAA region to the accidents that occurred in each for the period 1980 to 1985. For this analysis, OTA assumed that geography did not substantially influence the distribution of incident types (the ratio of incidents to accidents depends upon incident type). For the separate categories of air taxis, commuters, and Part 121 carriers, OTA found large regional biases for the ratio of total incidents to total accidents, varying from 78 to 1 to less than 1 to 2. For example, 7 percent of the Part 121 accidents and only 1 percent of the incidents occurred in the Alaska Region, while in the Great Lakes Region, 18 percent of the accidents and 33 percent of the incidents happened.

Most of OTA's sources, inside and outside of FAA, familiar with this incident database believed that it is not valid for analytical purposes. OTA's review of the database and data system confirm that the data should not be used for measuring changes in aviation safety. However, DOT's annual report to Congress pursuant to the Airline Deregulation Act,[34] as well as some journalists, have used AIDS incident trends in published analyses.

The Aviation Safety Reporting System offers an alternate source of incident information. Since reports are made voluntarily, and many pilots do not know of the existence of ASRS, it is difficult to determine the validity of trends in the data over time, although ASRS can provide insight into the underlying causes of incidents, especially the role of human factors. Consequently, while ASRS analyses can recommend preventive measures for certain classes of incidents, they cannot conclusively determine the rate of incident occurrences. However, ASRS offers supplemental information to other databases on trends and distribution of incidents such as NMACs and runway incursions. Moreover, unlike AIDS, the ASRS reporting format is designed to facilitate computer entry and analysis, the data are reviewed and encoded by experienced analysts, and numerous quality control procedures are used to ensure proper data processing.

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[32] Ibid, p. 3-68.

[33] Ibid, p. 3-100.

[34] U.S. Department of Transportation, *Annual Report on the Effect of the Airline Deregulation Act on the Level of Air Safety* (Washington, DC: February 1987).

OTA examined the relative prevalence of categories of ASRS incidents and compared them to accident data. NASA categorizes incidents by "primary problem," a classification quite similar to the "primary cause factor" used by Boeing in accident groupings. ASRS data indicate that from 1981 through 1986, the flight crew was the source of the primary problem in 69 percent of the air carrier incidents. Boeing's summary of worldwide commercial jet accidents from 1976 to 1986 also shows flight crew error as the primary cause in about 65 percent of the accidents.[35] Other categories do not match quite as well. ASRS data cite the aircraft and ATC/airports as the problem in about 6 percent and 22 percent of the reports respectively, while Boeing's analyses indicate that the aircraft accounts for 18 percent of the accidents and ATC/airports cause less than 5 percent. Such differences illustrate the errors that can be made in using the *number* or *percent* of incident reports to prove a point; nonetheless the incident reports are valuable analytic tools.

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[35] The National Transportation Safety Board's broad statistics cannot be used here as easily. Since *multiple* causes and factors are published instead of a *single* primary cause for each accident, Aviation Safety Reporting System and National Transportation Safety Board data cannot be compared by percentage.

ACCIDENT/INCIDENT CAUSAL FACTORS

The primary causal factors (see chapter 4) of accidents and incidents are aircraft capabilities, personnel capabilities, traffic environment, weather, and random events. However, all of these factors are not amenable to trend analyses. For example, while weather is a key factor in aviation safety, weather-related accidents usually stem from insufficient weather information or errors in human judgment. Most would agree that a serious degradation of aircraft, personnel, or traffic system capabilities would likely result in a decrease in safety and a need to develop countermeasures. Therefore, changes in these three causal areas offer early warnings for Federal and industry safety attention.

Aircraft Capabilities

Commercial aircraft[36] are designed and maintained to extraordinary standards, with multiple redundancies and wide operating margins. Although their components occasionally fail, few of the failures become serious accidents, and most component failures, even some that result in accidents, have a small direct impact on passenger safety. Indeed, most component failure accidents involve no collisions or crashes, and few fatalities. Aircraft component failure initiates 35 percent of the total accidents by Part 121 scheduled passenger carriers, but just 18 percent of the fatal accidents. Moreover, of the passenger airline fatal accidents initiated by component failures between 1975 and 1986, only one involved an airplane that had become unflyable.[37] Flight crew capabilities played a major role in the other accidents. On the other hand, each component failure indirectly affects safety—from distracting the flight crew to limiting the airworthiness of the aircraft.

FAA, airlines, and manufacturers collect detailed data on the mechanical reliability of commercial aircraft, and the databases show many improving, and few adverse, trends in aircraft reliability. Because of close monitoring of aircraft performance, and the economic incentive to the airlines and manufacturers, aircraft component reliability problems are solved quickly.

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[36] Transport category airplanes (see 14 CFR 25), such as the jetliners common to the major air carriers, are the only ones explicitly considered in this section. Aircraft certificated under 14 CFR 23, SFAR 23, and SFAR 41, such as those used by commuter and regional airlines, were not addressed.

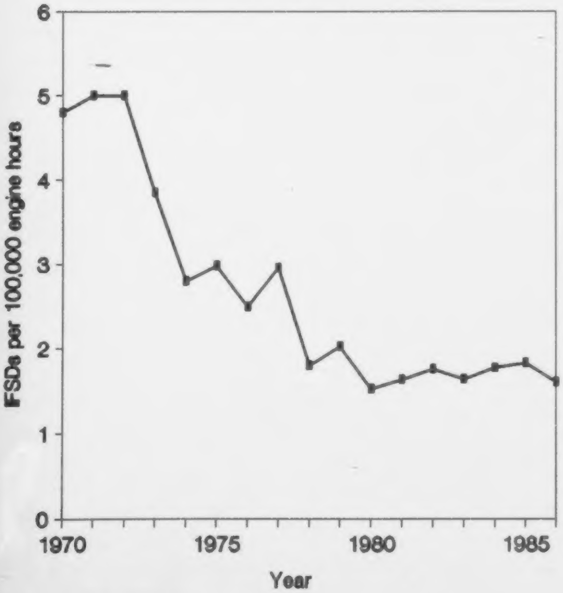
[37] DC-10 accident, Chicago, IL, May 25, 1979.

Engine Shutdown and Failure Rates

Modern jetliners are capable of operating safely, even in the unusual event of an engine failure in any phase of flight; indeed, engines are sometimes shutdown in flight as a precautionary measure if a problem is detected or suspected. All in-flight engine shutdowns must be reported to FAA; the airframe and engine manufacturers also keep close tabs on these data.

The engine shutdown rate declined for U.S. jet fleets during the past decade, with the current engine shutdown rate for the familiar B-727s, B-737s, and DC-9s, falling to about half the rate of the mid-1970s.[38] (See figure 5-6.) A more critical subset of these events, engine noncontainments[39] for a specific aircraft type, occur fewer than 10 times per year worldwide. These are broad statistics; specific engine model series, as well as individual air carrier maintenance practices, should be considered in engine reliability analyses. However, these data show that overall, engine reliability is not a problem.

Figure 5-6.—Basic In-flight Shutdown (IFSD) Rate, (domestic operators only) B727/JT8D Engines



SOURCE: Office of Technology Assessment based on Boeing Commercial Airplane Co. data.

Safety Reliability of Other Components

The airframe manufacturers collect data on the failure rates of other aircraft parts, such as hydraulic, pressurization, and electrical systems. OTA obtained data for worldwide fleets only,[40] but they showed that these events also occur infrequently. In-flight pressurization loss and single system electrical power loss happen about 5 times each in a million flight-hours. The trends over time for these events are shallow, and depending on the aircraft type, increase or decrease. Single system hydraulic power loss occurs more frequently (about 60 events per million flight-hours in 1986), but the rates have consistently declined for all the Boeing models.

Airlines are required[41] to report certain aircraft failures, defects, or malfunctions to FAA. This information, along with reports from independent maintenance and repair facilities, are entered into FAA's Service Difficulty Reporting System (SDRS). The large volume of SDRS data enables FAA to identify aircraft mechanical problems that could otherwise go unnoticed. However, FAA does not enforce the reporting requirements or verify the accuracy of the data. While SDRS data trends are useful as problem alerts, they do not constitute sound measurements of aircraft component reliability changes.

Unscheduled Landings

Due to the cost involved[42] and the inconvenience to the passengers, an airline will divert a flight to an airport other than the final destination only if a serious event occurs. While some unscheduled landings, resulting from weather-related airport closures or passenger medical emergencies, are beyond the control of the airline, maintenance or operating practices may cause mechanical-related flight diversions. If the criteria for deciding on whether to divert remain consistent, trends in mechanical-related unscheduled landings will give one indication of changes in the reliability of critical aircraft components. FAA requires that airlines report all unscheduled landings due to mechanical difficulties or malfunctions. However, since these reports are part of SDRS, the problems with database validity discussed above apply.

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[38] Federal Aviation Administration Air Carrier Aircraft Utilization and Propulsion Reliability Reports and Boeing Commercial Airplane Co. data.

[39] A noncontainment occurs when an engine component fails and penetrates the outer casing of the engine.

[40] Boeing data.

[41] 14 CFR 121.703 and 121.705 (Jan. 1, 1987).

[42] For example, the average direct operating expense for Boeing 727-200s in air carrier service is over $2,100 per hour.

OTA examined unscheduled landing data from the SDRS database. A comparison of the unscheduled landing rates (reported events per departure) for the major carriers revealed differences as great as a factor of 12 among them.[43] OTA obtained some data, which are assumed to be accurate, directly from a few airlines. The FAA data on unscheduled landings ranged from more than 80 percent below the airline records in one case to 12 percent above in another. OTA concludes that this subset of SDRS data, as currently kept, cannot be used for trend analysis or comparisons among airlines.

Boeing also keeps unscheduled landing data, but the data for U.S. operators was limited. The unscheduled landing rate for the B-747 (the only type with available data) steadily declined since its introduction, falling by half since the mid-1970s.

Personnel Capabilities

Theoretically, human performance reliability could be measured in a similar manner, but data collection on these capabilities is difficult, especially in the operating environment. Human capabilities such as motor skills, alertness, and cognitive skills (for example, decisionmaking and judgment) are believed to play major roles in human error-caused aircraft accidents. Selection, training, experience, and working conditions, as well as physiological, psychological, and sociological status, affect the capabilities of the aviation system work force. However, the magnitude and direction of the interrelationships between and among these factors is poorly understood. Current data on the underlying human failure causes that culminate in accident-causing errors are studied by only a few experts. Consequently, identifying, developing, and implementing countermeasures is hampered by limited understanding of effective ways to modify human behavior and attitudes.

Since human error is involved in the majority of commercial aviation accidents, better collection and analysis of data on human capabilities and failures is the cornerstone of future gains in aviation safety. Additionally, research and data collection to identify innovative and effective human error countermeasures is essential.

Traffic Environment

About 20 percent of the Part 121 fatal accidents, and less than 5 percent of total accidents, result from traffic environment factors.[44] Traffic environment factors include the reliability of the ATC system and airport and airway facilities, along with air traffic levels and mixes. Any one, or several of these variables may be involved in any given accident. However, the traffic environment accidents that fall into specific categories, such as midair collisions or those caused by ATC errors, are so rare that trends cannot be determined.

MANAGEMENT PRACTICES

Managerial practices, from corporate policy-setting to pilot decisionmaking, affect airline safety. The selection and training of employees and the maintenance and operation of vehicles and equipment are major components of the performance capabilities of the aviation system. While FAA sets standards and conditions for these practices, individual airline procedures to meet these guidelines vary widely. This section describes changes in industrywide practices since deregulation, and highlights significant differences among carriers.

Currently, FAA evaluates management practices through inspections, such as the on-site audits. Ideally, the FAA inspector becomes familiar with the details of an airline's operations and is knowledgeable about practices at other carriers. FAA uses inspections primarily for coaching and disciplining airlines, rather than analysis, and has kept few historical records of inspections.[45] Consequently, FAA has no systemwide qualitative data on airline management practices or changes in them. Moreover, many of the results or effects of management practices are not investigated or are unmeasurable, and the complex interactions of management processes leave few clear cause-and-effect trails.

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[43] These differences usually go unnoticed, since Federal Aviation Administration inspectors review data from their respective carriers only.

[44] OTA analysis of National Transportation Safety Board accident briefs.

Seeking supplementary sources for information about changes in management practices over the past decade, OTA examined economic data reported by the airlines, such as flight schedules and maintenance expenses. Additionally, OTA solicited answers to a confidential survey from airline pilots, mechanics, and company officers, and through a contractor, conducted case studies supplemented by on-site interviews with four airlines.

Maintenance

As controlling operating costs became increasingly important, attention focused on whether economic pressures would force carriers to cut corners on maintenance. OTA found that maintenance expenditure data for the major carriers show no evidence that airlines unduly cut costs. Moreover, the

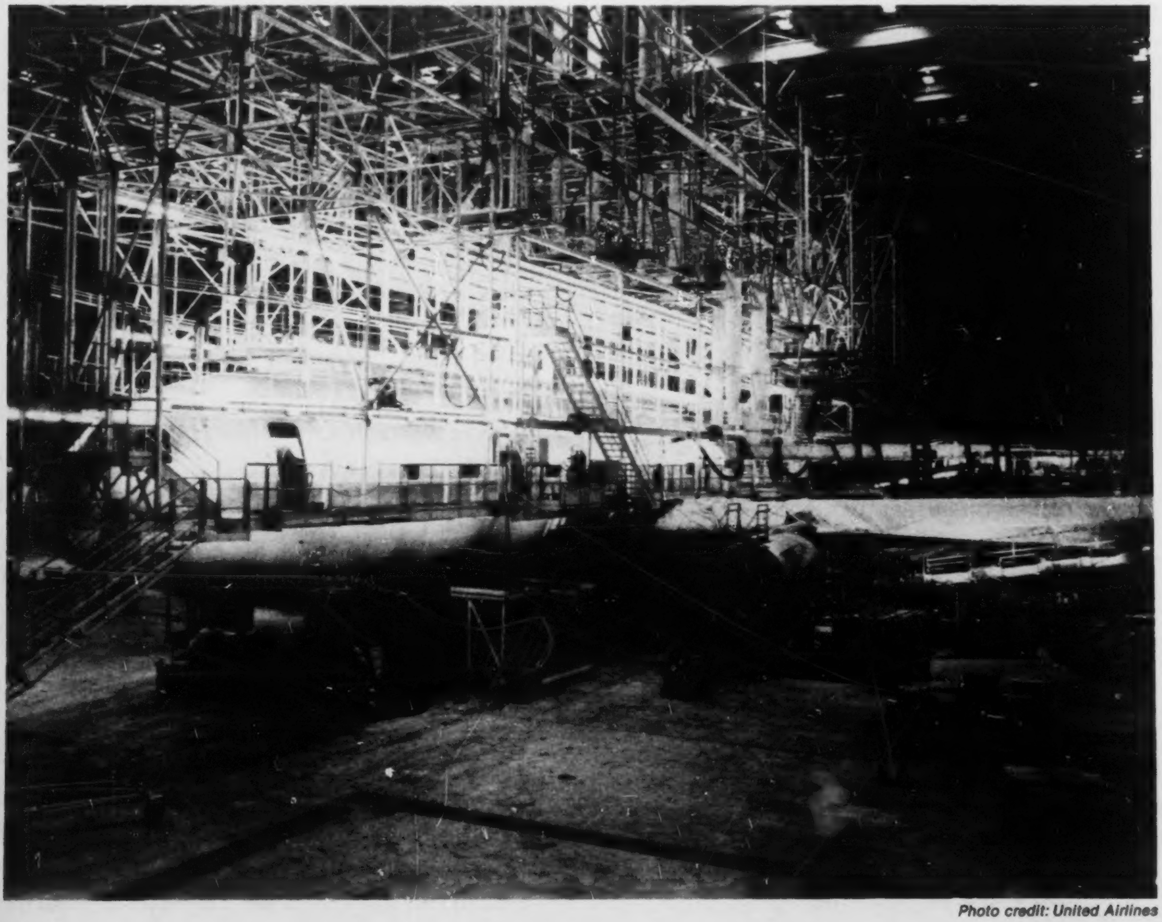

Photo credit: United Airlines

Commercial transport aircraft undergo extensive periodic maintenance.

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[45] U.S. Congress, General Accounting Office, *Aviation Safety: Needed Improvements in FAA's Airline Inspection Program Are Underway*, GAO/RCED 87-62 (Washington, DC: May 1987), pp. 24-38.

accident record for the large airlines and data on aircraft mechanical reliability reflect no increase in aircraft system failures, as might be expected if maintenance quality had deteriorated.

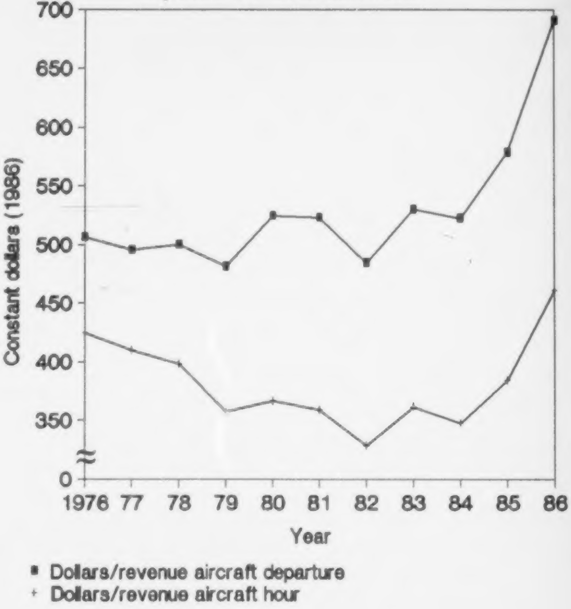
Declines in maintenance expense as a percentage of total operating expense are not good measures of changes in the quality of airline maintenance. Technological advances and efficiencies from modern maintenance inspection devices and inventory management systems affect maintenance expense, while fuel costs and nonmaintenance labor are large and widely fluctuating contributors to operating costs. Maintenance expense trends for specific aircraft types and models are more meaningful. Additionally, since maintenance requirements depend on the amount of aircraft use, expense data should be normalized by flight hours or departures.

Industry-wide on average, flight equipment maintenance expenses (in constant dollars) for specific aircraft models have increased since the early 1980s (see figure 5-7). Due to differences in accounting methods, route structure, and fleet size and age, maintenance expenditure comparisons among individual airlines must be viewed cautiously. OTA examined data for the eight major air carriers that operated the Boeing 727-200 during the past decade (1976 to 1986), since the B727-200 was the most common aircraft model over that period. For each airline, the trends in maintenance costs per flight-hour and per departure have increased since 1982 and reached the highest levels of the decade in either 1985 or 1986.[46]

OTA identified three broad maintenance-related changes within the airline industry that warrant future attention. The quality of maintenance is affected by more contract maintenance, more aircraft leasing instead of owning, and more flight operations and tighter schedules.

Major carriers have consistently contracted with outside companies for about 11 percent (based on dollars spent) of their maintenance needs, while the smaller national carriers contract for about 40 percent. The rapid growth of the national carrier segment of the industry (over 250 percent in flight-hours in 10 years v. 21 percent for the majors) caused the total contract maintenance use for the industry to increase from 12.5 percent in 1983 to 16 percent in 1986. While contract maintenance should not be any less safe than in-house maintenance, it places an important aspect of a carrier's safety network in another company's hands. Airlines, by regulation, must provide their own inspectors to monitor contractors' work, as the responsibility for airworthiness rests with the operator of the aircraft. Contract maintenance, by its nature, is not as easy as in-house work to monitor and manage.

Figure 5-7.—Average Flight Equipment Maintenance Expense for B727-200 Fleet[a]



[a]Major carriers only.

SOURCE: Office of Technology Assessment based on Research and Special Programs Administration data.

The number and value of aircraft in scheduled and charter services that are not owned by the carriers operating them has grown significantly. OTA estimates that over half of all aircraft transactions for new and used planes in the United States since 1984 involved leases. In 1986, leasing companies bought 10 percent of the total output of Boeing and Douglas; orders were expected to grow to 14 percent in 1987. Since the aircraft's long-term value is not theirs to preserve, some operating carriers changed some aspects of their maintenance programs. For aircraft nearing the end of their leases:

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[46] One airline had its highest expense levels with respect to departures only and not to flight-hours.

- periodic inspections are used in lieu of permanent fixes for complying with airworthiness directives when possible;
- engines, airframes, landing gear, and other life-limited components (replaced after a fixed number of hours or landings) are near the ends of their estimated lives; and
- corrosion is treated only to the degree required.[47]

Cost reductions such as these affect economic maintenance primarily, as opposed to airworthiness maintenance. For example, an aircraft that has been flown up to a major overhaul requirement can be worth as much as 65 percent less than one that is progressively and currently maintained.[48] While leased aircraft meet airworthiness standards, the question remains open as to whether operator-owned aircraft that may receive more extensive maintenance are safer. No industry-wide data are currently available that compare the safety impact of operator-owned aircraft maintenance to leased aircraft maintenance.

Precise flight schedules are required for efficient operation of hub and spoke systems. OTA research corroborated press reports that pilots and mechanics feel pressure, implicit and, in some cases explicit, to overlook mechanical problems to prevent delays. In addition, special FAA maintenance surveillance conducted in 1987 found that a few airlines improperly deferred maintenance regarding minimum equipment lists, a problem FAA addressed in spring 1988 by tightening required procedures. Finally, OTA research indicates that several airlines do occasionally postpone maintenance, and many choose lower levels of maintenance when cash flow is a problem or when using leased aircraft.

Operations

The major operating changes in commercial aviation over the past decade were the expansion of hub and spoke systems and the record growth in flights by the major, national, regional, and commuter airlines. The primary impacts are that airports have reached their traffic capacity limits, and airline schedules have increased demands on the air traffic system equipment, facilities, and personnel, creating traffic congestion and delays (see chapter 7). Additionally, operating practices affect the number of flight-hours and departures experienced by each airline's pilots and aircraft.

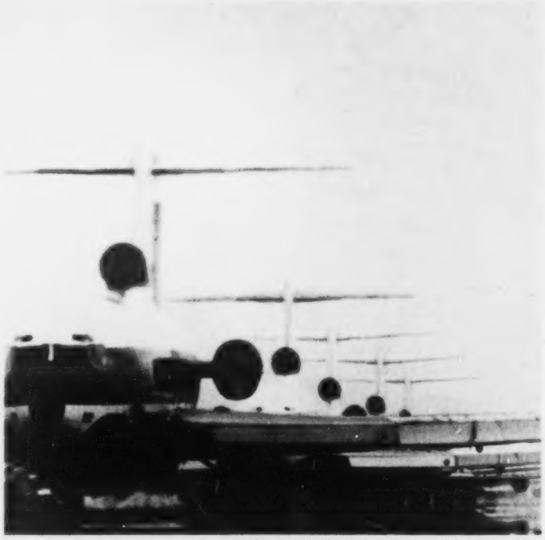

Photo credit: Federal Aviation Administration

Rapid growth in air travel has placed heavy demands on aviation equipment, facilities, and personnel.

Since the early 1980s, the airlines, on average, have increased the number of flight-hours and departures per aircraft per day, although current utilization rates are generally below 1979 levels for aircraft types in existence before deregulation. Since maintenance requirements are primarily flight-hour or cycle dependent, increased utilization necessitates more frequent maintenance on a calendar basis. Additionally, the major airlines have increased the productivity of their mechanic work forces. Seven of the 10 major carriers in existence at the end of 1986 operated more flight-hours per mechanic recently (1983-86) than they did prior to deregulation.

Of greater concern is the effect of increased hours and departures per day on pilot performance. While FARs set limits on flight-hours over various time periods, they do not address duty-hours or departures, both of which affect pilot fatigue and are covered in the aviation regulations of other countries. (See chapter 6.) Few airlines keep track of pilot duty time; the pilots from five out of eight large airlines responding to OTA's survey indicated that duty time has increased or become more inconvenient since deregulation. On the other hand, pilot flight-hours have not changed much, since they have remained close to the upper limits established either by labor contracts or Federal regulations. Other environmental factors, such as operational complexity and traffic density, also affect pilot fatigue. However, recent considerable gains in the understanding of fatigue have not been transferred to the operating setting.[49]

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[47] Simat, Hellieson, and Eichner, "Safety of the Air Transportation System in a Deregulated Environment," OTA contractor report, October 1987.

[48] Ibid.

Hub and spoke systems require finely tuned flight schedules—a single flight cancellation or delay can disrupt the flight connections for passengers in many cities. Self- or management-induced pressures to meet schedules may adversely affect pilot performance and decisionmaking. One pilot stated that he believed intimidation was the intent when his airline made computer checks of pilots' maintenance entries in the aircraft logbooks; those who were perceived by management as making too many entries were called into the chief pilot's office and required to justify their actions. The effects of such stress factors are difficult to quantify. See chapter 6 for further discussion of the effects of stress.

Regional/Commuter Airline Operations

According to RAA, consolidation of the commuter and regional airlines is expected to continue into the early 1990s, with two-thirds of currently operating airlines merging or failing and many becoming wholly or partly owned by the large airlines.[50] This development can be beneficial for safety if the parent company imposes strict operating and maintenance requirements on closely linked affiliates. For example, Allegheny Airlines (now USAir) formed the Allegheny Commuter System in 1967 and required that member airlines adhere to standards more stringent than FAA's in return for marketing, scheduling, and financial services. From 1970 to 1980, the Allegheny Commuters had a better safety record than the jet carriers.[51]

Some major carriers have placed regional pilots on their seniority lists and guaranteed future employment opportunities. Pan Am established such an arrangement after purchasing Ransome Airlines (now Pan Am Express); the pilot turnover rate went from 12 percent per year to approximately zero.[52] Continental Airlines, which owns Britt Airways, PBA, Rocky Mountain Airways, and a major interest in Bar Harbor Airways, established a commuter division to coordinate aircraft purchases and pilot training. Continental plans to replace the 20 types of aircraft used by its affiliates with just 3 types and to the standardize the training of mechanics and pilots. Additionally, Continental is using its regional airlines to train pilots for the parent company. For example, some new hires fly as flight engineers on Continental for 1 year, then become co-pilots on a Continental Express aircraft, and finally move up as co-pilots at Continental (although some will fly as captains at the regional first).[53]

One conclusion of FAA's National Air Transportation Inspection program was that ". . . a significant change in operations of an existing carrier, such as a change in range of operation or in size of aircraft flown . . . can provide a warning signal for potential problems."[54] Yet the principal inspector assigned to a Part 135 commuter often is responsible for a number of other airlines. For example, the principal operations inspector for one commuter airline testified before NTSB that he did not have time to carry out his oversight tasks effectively because he was responsible for 20 other certificate holders.[55] While the expected consolidation of regional/commuter airlines may ease some of FAA's workload in the future, the ensuing turmoil as the reorganization takes place warrants close FAA attention. Moreover, the upturn in the commuter accident rate for 1987 is noteworthy; in only one other year since 1978 did the rate increase from the previous year.

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[49] R. Curtis Graeber, National Aeronautics and Space Administration, Ames Research Center, personal communication, Mar. 2, 1988.

[50] *Aviation Week & Space Technology*, "Economics, Code Sharing Threaten Survival of Commuter Airlines," Apr. 27, 1987, p. 57.

[51] Clinton V. Oster, Jr. and C. Kurt Zorn, "Commuter Airline Safety," *Deregulation and the New Airline Entreprenuers*, John R. Meyer and Clinton V. Oster, Jr. (eds.) (Cambridge, MA: The MIT Press, 1984), ch. 5.

[52] Tim Cwik, director of operations, Pan Am Express, personal communication, Mar. 10, 1988.

[53] *Aviation Week & Space Technology*, "Regional Airlines Play Key Role in Continental's Pilot Development," Nov. 16, 1987, pp. 40-41.

[54] U.S. Department of Transportation, Federal Aviation Administration, "National Air Transportation Inspection Program," report for the Secretary, Mar. 4 - June 5, 1984, p. 36.

[55] Jim Burnett, chairman, National Transportation Safety Board, "Safety Recommendation to Federal Aviation Administration," letter, Oct. 9, 1986, p. 7.

Employee Selection and Training

Aviation professionals—pilots, controllers, mechanics, and others—are the key components of the air safety system. Their skills and flexibility prevent countless mishaps each day, while their mistakes are dominant factors in aircraft accidents and incidents. Employee selection and training are important methods used by the airlines and the Federal Government for controlling human errors, though they are not panaceas (see chapter 6). Airline flight crew selection and training have changed markedly in the past decade.

Selection

Although flight crew hiring declined between 1979 and 1982, strong traffic growth brought record demand for pilots, and more pilots have been hired since 1983 than in the period from 1967 to 1983. Data collected by the Future Aviation Professionals of America indicate that, on average, a greater percentage of new hires have no military experience, have less than 2,000 hours total flight-time, have no jet or turboprop experience, and have no airline transport pilot or flight engineer certificate. Airlines are also relaxing requirements for age, education, eyesight, and physical size.

Examined by airline type, these changes are more pronounced (see table 5-7). The most notable change[56] for the major carriers is that new hires with less than 2,000 total flight-hours have increased from less than 2 percent to more than 13 percent. For the nationals, the number of new cockpit crew members with military experience[57] has dropped from 82 to 34 percent. At other jet carriers and regional airlines, 29 percent of the new hires have no jet or turboprop experience, compared to less than 3 percent at the larger airlines. Finally, the number of new pilots at the regional carriers with less than 2,000 hours of total flight-time increased from less than 9 percent to 29 percent.

Flight-time or military background, although used for years by the airlines, are only rough estimates of actual pilot skills. Developments in aircraft and training technologies may correct some deficiencies in pilot experience. Accident statistics for the large airlines show no correlation with pilot experience; no aircraft involved in an accident since 1976 was flown by a captain with 2,500 hours or less of flight-time. Actual experience in a specific aircraft type and airline might be more predictive of accident risk. However, OTA is aware of no studies in this area, though NTSB and FAA have warned against pairing inexperienced captains with inexperienced copilots.

The rapid growth of the large carriers has meant increased competition for limited resources, a battle the regional/commuter can rarely win. The demand for more commercial airline pilots places additional pressure on the regional/commuters: they must compete for new hires and at the same time see a large number of their trained pilots leave for the high paying majors. Some small airlines have experienced pilot turnover rates exceeding 100 percent per year.

Training

A comprehensive analysis and qualitative comparative assessment of employee training programs across the airline industry is beyond the scope of this study. The best source for such information would be FAA inspections and audits; however, these data are presently unavailable or inaccessible.

Table 5-7.—Qualifications of New-Hire Commercial Flight Crews (percent, by year)

	Major airlines		National airlines		Other jet airlines		Regional airlines	
Pilots with	1983	1986	1983	1986	1983	1986	1983	1986
Less than 2,000 hours total flight time	1	13	0	11	14	12	9	29
No military experience	46	56	18	66	55	70	83	88
No jet or turboprop flight time	1	2	1	6	24	29	32	28
No air transport pilot certificate and no flight engineer certificate	18	26	24	41	42	56	77	76

SOURCE: Office of Technology Assessment based on Future Aviation Professionals of America data, as of May 1987.

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[56] All changes are for the period 1983 to 1986.

[57] The airlines regard military backgrounds highly. The military services have rigorous pilot selection and training requirements; only the most skilled and motivated pilots earn their wings.

However, from the aspect of cockpit management and decisionmaking, the "can do" attitude instilled in the military flyer is not appropriate if applied to commercial passenger operations.

OTA relied upon case studies of selected carriers and the responses to survey questionnaires for insight on quality differences over time and among the airlines.

After a series of highly publicized incidents and increased attention by labor unions to airline training programs, FAA announced an initiative to examine FARs dealing with pilot training. Whether or not the quality of training at some airlines has declined recently, over the past 15 years training has substantially improved. Sophisticated, full-motion simulators used by all the major carriers, or other advanced training devices, allow training scenarios (e.g., flight into severe weather, engine fires, or other extreme emergencies) that could never be permitted in actual training aircraft. Cockpit crew management is a significant factor in a number of air carrier accidents, and crew coordination training, used in conjunction with simulations of operational flights with full crews, adds an important dimension to the background of the modern airline pilot.

At least three U.S. carriers are establishing programs at universities to take pilot candidates with no aviation experience and prepare them for airline careers. General aviation training has dwindled in recent years—the number of private pilot certificates that were issued in 1986 represented a 35 percent drop from the 52,000 issued in 1982. This reduction has come at a time when the airlines are drawing fewer of their pilots from the military. Moreover, early training and experience has a strong influence on a pilot's future performance—even after he has received advanced training.[58]

While most airlines claim to have cockpit resource management or line oriented flight training programs, OTA's research indicates that relatively few pilots experience them. United Airlines and Pan Am are the only carriers with formal, annual crew coordination training programs using full mission simulation for all flight crew members. Most of the pilots surveyed felt that present recurrent training programs are insufficient; however, all confirmed that the training is consistent with current regulations.

Mechanics from three airlines indicated to OTA that they believed that present Federal standards for maintenance training are too low—for example, recurrent training is not required for aircraft mechanics or inspectors. At one carrier, the number of maintenance instructors was cut by 75 percent.

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[58] Frank Monastero, T.M. Monitor Corp., personal communication, Mar. 7, 1988.

MANAGEMENT POLICIES

"Safety begins at the top" is an accepted maxim throughout aviation. Senior corporate officials set the safety framework within their organizations by the policies they establish. Although airline and government officials alike profess a willingness to pay any price for safety, in reality, this is impractical. While safety is an important passenger concern, convenience and cost are the primary variables that determine demand for air transportation.[59]

Cost control is critical to the success of any organization, and safety, like fuel, maintenance, or advertising, has a cost. However, safety costs are rarely defined clearly, since management of each element in a system plays a role in safety.

In recent years, a number of airlines have eliminated or cut back engineering, weather, medical, and safety departments, thereby shifting some safety responsibilities within the company and moving other tasks outside the company. While changing aspects of a redundant safety system may reduce safety, a number of questions need to be answered before such actions cause undue alarm. If marginal improvements in other safety areas balanced the loss, two layers of redundancy in 1988 could be more effective than three layers in 1978, for example.

Since corporate actions are many steps removed from accident rates, identifying a clear cause-and-effect relationship may be impossible, although one measure of corporate safety policy might be relative compliance with safety regulations. Adherence to Federal regulations gives an indication of corporate attitude or competence, both critical with regard to safety. While FAA has records of the enforcement actions taken against carriers that violated regulations, no records have been kept on the amount of inspection activity each carrier experienced over time, preventing calculation of a valid violation rate.[60]

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[59] Robert W. Simpson, Flight Transportation Laboratory, Massachusetts Institute of Technology, "A Theory for Domestic Airline Economics," unpublished manuscript, January 1977.

CONCLUSIONS AND POLICY OPTIONS

On the basis of its review of accident data, OTA concludes that commercial aviation safety in the 1980s continues to be excellent. However, human errors are the predominant causes of over 65 percent of all accidents that do occur, and this distribution has not changed in recent years. Moreover, weather-related accidents from unexpected severe conditions often involve faulty decisionmaking or communications. Aircraft component failures, factors in over 40 percent of total accidents, are often compounded by human error.

OTA examined numerous nonaccident safety databases for indications of changes in safety risk. While inadequacies in data collection and management or the nature of the safety events limit the validity of such data, nonaccident databases in three categories—ATC environment, aircraft reliability, and human performance—can contribute to aviation safety policy decisionmaking. For example, while data on aircraft component failures indicate improving aircraft system reliability, airline flight operations, especially scheduling and timing, have caused record levels of air traffic and controller workload in recent years. Increases in commercial aviation traffic correspond closely to the rise in reported NMACs, suggesting that future traffic growth is a cause for concern.

The four major causal factors in commercial aviation accidents are human performance, weather, aircraft component failure, and the air traffic environment. OTA concludes that the greatest potential for additional safety problems lies in the areas of air traffic, as continued vigorous traffic growth and increased traffic densities for longer periods of time at more airports could outstrip the capabilities of the traffic system. However, continuing gains in aircraft mechanical reliability and in understanding and coping with severe weather could well outweigh the effect of even a sizable decline in air traffic safety. The rate of pilot error-caused accidents has remained constant for the past decade and few data on pilot performance have been collected and analyzed from the operating environment, making reliable predictions of future trends difficult.

OTA concludes that if Congress wishes to improve commercial aviation safety significantly, enhancing human performance is a top priority. Civilian aviation in the United States lacks a long-term human performance research and development program. While innovative research is best done outside of a regulatory agency, FAA could serve as the focal point and catalyst for cooperative efforts at understanding human performance and the factors influencing it and communicating the findings to the aviation system operators and managers. In the short term, the resources and understanding within FAA, NASA, the Department of Defense, universities, industry, and special interest groups could be combined in advisory working groups. These could provide guidance for developing and disseminating training procedures for upgrading crew coordination and decisionmaking.

An important research area is the optimal design and procedures for use of automation in the cockpit and in ATC facilities. Analyses of human errors and their causes need to be implemented in the airworthiness and operating standards for aviation systems and organizations.

Increasing the capability to predict and detect severe weather such as windshear and communicate this information to the cockpit is another pri-

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[60] For further information on the potential uses of Federal Aviation Administration inspection data records for measuring airline safety, see U.S. Congress, General Accounting Office, *Aviation Safety: Measuring How Safely Individual Airlines Operate*, GAO-RCED-88-61 (Washington, DC: March 1988).

ority. Data also indicate that air traffic safety will be further improved with the introduction of collision avoidance equipment and the expansion of Mode C transponder requirements. Safety could be upgraded through the addition of conflict alert capabilities at large radar terminals and the development of ground collision alert and runway intrusion detection systems for airports.

Airline management operating practices, along with the ATC system, are the control valves for commercial aviation safety. Maintenance expense data show increased spending (in constant dollars) across the industry during the past 5 years. Some airlines have lowered hiring standards, increased duty time, and increased employee stress through reorganizations and wage cuts. However, the effects of these and other management practices on human performance, and subsequently on system safety, are difficult to quantify. FAA's inside view of airline management procedures through periodic and unannounced audits and inspections is critical for assessing the relative safety value of airline management procedures and any changes over time.

OTA concludes that Federal oversight, through standards, inspections, and enforcement is key to upholding air carrier maintenance reliability and operating safety. Three FAA responsibilities need continued support: the training program for inspectors, work force levels sufficient to match changes in industry operating patterns, and automated systems for tracking and analyzing FAA-collected data and airline computerized records. Based on the operating and marketing changes underway, the Part 135 commuter industry warrants the most critical FAA oversight during the shakeout expected over the next few years. While it is too early to draw conclusions regarding patterns or causes for 1987 commuter accidents, last year's upturn in accidents is noteworthy; in only one other year since 1978 did the accident rate increase from the previous year.

Improved safety data collection and analysis by FAA would permit better Federal understanding of developing aviation safety problems. While FAA analyzes air traffic safety data and is upgrading its collection and management of inspection data, the agency could benefit greatly from analysis of air carrier-related safety data, such as operating practices and all types of incidents. FAA principal inspectors have a good understanding of their respective air carriers' safety postures; but they are often unaware of the activities at other airlines. Additionally, FAA requires only that airlines meet minimum Federal standards; FAA might consider encouraging airlines to strive to improve their safety posture above the base level. **A program to consolidate and communicate the safety knowledge from each principal inspector and airline would do much to enhance safety.**

Chapter 6

The Human Factor in Commercial Aviation

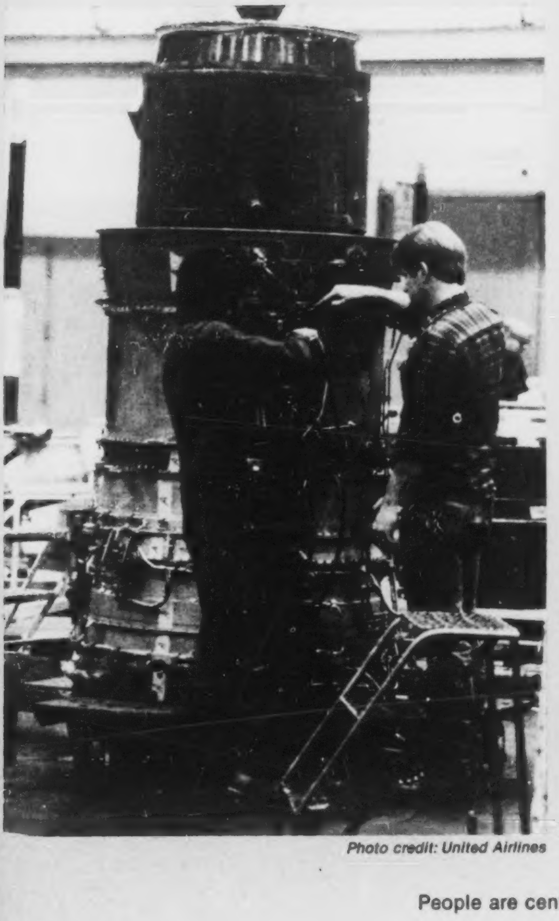


Photo credit: United Airlines

Photo credit: The Singer Co.

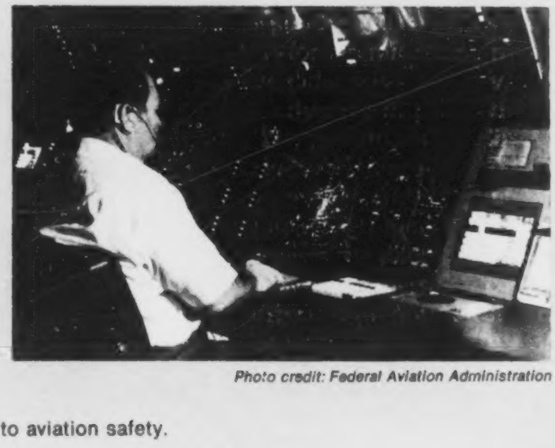


Photo credit: Federal Aviation Administration

People are central to aviation safety.

CONTENTS

Page
Human Error 118
  Preventing Errors 119
  Compensating for Errors 120
  Human Factors Data 120
Industry and Federal Roles in Human Factors 121
  Growing Concerns 121
  Federal Responsibilities 127
  Industry Responsibilities 129
  Labor's Role 131
Conclusions and Policy Options 131

Box

Box *Page*
6-A. Air Traffic Control Automation 125

Figure

Figure *Page*
6-1. Part 121 Total and Human Error-Caused Accidents 117

Table

Table *Page*
6-1. Significant Jetliner Accident Causes in 93 Major Accidents Worldwide (1977-1984) 117

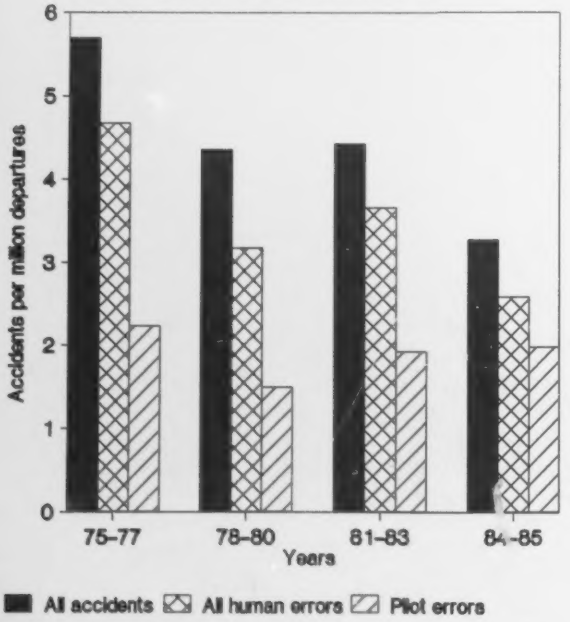
Chapter 6

The Human Factor in Commercial Aviation

The people who operate and support the U.S. aviation system are crucial to its safety; the resourcefulness and skills of crewmembers, air traffic controllers, and mechanics help prevent countless mishaps each day. However, despite the fact that the total accident rate for large jets declined over the past decade, the National Transportation Safety Board data show that the rate of accidents involving pilot error did not change (see figure 6-1). Policy, procedures, or technology designed to reduce human error would substantially influence safety, as human error is a factor in over 65 percent of commercial aviation accidents.

An analysis of major accidents involving large, commercial transports, identified flight crew errors as the leading significant causal factors in these accidents.[1] For accidents having multiple causes (over 70 percent in this analysis), reducing the likelihood of one causal factor reduces substantially the overall probability of the accident occurring. As shown in table 6-1, flight crew causes predominate, although other human errors are elements of many

Figure 6-1.—Part 121 Total and Human Error-Caused Accidents



SOURCE: Office of Technology Assessment based on National Transportation Safety Board data, 1975-85. Data from 1986 and 1987 are not yet available.

Table 6-1.—Significant Jetliner Accident Causes in 93 Major Accidents[a] Worldwide, 1977-84

Causal factor	Percent of accidents
Flight crew causes:	
Pilot deviated from basic operational procedures	33
Inadequate crosscheck by 2nd crew member	26
Captain did not respond to crew inputs	10
Crews not conditioned for proper response during abnormal conditions	9
Pilot did not recognize the need for go-around	6
Deficiencies in accepted navigation procedures	4
Pilot incapacitation	4
Inadequate piloting skills	4
Pilot used improper procedure during go-around	3
Crew errors during training flights	3
Pilot not trained to respond promptly to ground proximity warning system command	3
Pilot unable to execute safe landing or go-around when runway sighting is lost	3
Operational procedures did not require use of available approach aids	3
Captain inexperienced in aircraft type	3
All other causes:[b]	
Design faults	13
Maintenance and inspection deficiences	12
Complete absence of approach guidance	10
Air traffic control failures or errors	9
Other	9
Weather information insufficient or in error	8
Runway hazards	7
Air traffic control/crew communication deficiencies	6
Weight or center-of-gravity in error	5

[a] A major accident involves either a fatality or a hull loss.

[b] Includes other human errors, equipment failures or problems, weather, maintenance, and airport facilities.

SOURCE: Office of Technology Assessment based on Richard L. Sears, Boeing Commercial Airplane Co., "A New Look at Accident Contributors and the Implications of Operational and Training Procedures," *Influence of Training, Operational and Maintenance Practices on Flight Safety*, Proceedings of the Flight Safety Foundation's 38th Annual International Air Safety Seminar (Arlington, VA: Flight Safety Foundation, Nov. 4-7, 1985), pp. 29-51.

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[1] Richard L. Sears, "A New Look At Accident Contributors and the Implications of Operational and Training Procedures," *Influence of Training, Operational and Maintenance Practices on Flight Safety*, Proceedings of the Flight Safety Foundation's 38th Annual International Air Safety Seminar, Nov. 4-7, 1985 (Arlington, VA: Flight Safety Institute, 1985).

of the remaining causes. OTA analyses of accident data (see chapter 5) found that human errors initiate over half of U.S. jetliner accidents. Additionally, OTA found that most of the fatal accidents caused by aircraft component failure also involve human error.

Post-accident investigations usually uncover the details of *what* happened. In the case of mechanical failures, accident data analysis often leads logically to *why* the accident occurred. It is much more difficult to determine the precise reason for human errors. Without an understanding of human behavior factors in the operation of a system, preventive or corrective actions are impossible.

Human factors understanding is especially important to systems in which humans interact regularly with sophisticated machinery and in industries where human error-induced accidents can have catastrophic consequences. However, human factors is not treated as a "core" or "enabling" technology in commercial aviation. Technical decisions for aircraft design, regulation, production, and operation are based on "hard" sciences such as aerodynamics, propulsion, and structures. Human capabilities do not lend themselves readily to consistent, precise measurements, and human factors research requires much more time and cooperation than most other aeronautics research.[2] Data on human performance and reliability are regarded by many technical experts as "soft," and receive scant attention in some aviation system designs, testing, and certification. When data are used in designs, it is often after the fact. This chapter explores areas of aviation safety where human factors are especially important and evaluates Federal programs to address human factors in accident prevention.

HUMAN ERROR

The role of the human in an aviation system is complex; thus the nature of human errors, from mental to physical, in aviation accidents varies widely. Mental or cognitive errors can include improper judgment or decisionmaking, while physical errors may stem from motor skill deficiencies or equipment design. A combination of physical and mental processes may influence other kinds of errors, such as those involving communication, perception, or alertness.

Many types of human error are systematic, following certain predictable patterns; once these patterns are identified, countermeasures can be developed. For example, accidents due to pilots' forgetting to extend landing gear have been virtually eliminated in commercial operations by the introduction of cockpit warning devices.

Much of the discussion in this chapter focuses on fundamental human factors: how the interactions of people, machines, and environment influence the performance capabilities of physically fit, emotionally stable, human operators. However, management practices, such as labor relations and work scheduling, also affect employee stress and fatigue. While conditions that affect a person's fitness and mental health generally influence his performance limitations, little is known about the magnitude of this relationship. Concerns about aviation management practices are addressed later in this chapter.

For those types of human error that do not follow predictable patterns, intervention techniques and limitation methods are difficult to develop. Furthermore, any change to a complex system like aviation safety can have wide-ranging and often unpredictable effects; thus, there are few simple solutions to the problem of human error-caused mishaps. Nonetheless, the options fall into two main categories: preventing or limiting the number of errors, and compensating for errors that occur. This section will outline the methods used or available at present and serves as the basis for later discussion of many needed changes in Federal human factors policies.

Preventing Errors

While preventing all human error is impossible, error rates can be reduced. In aviation, as in other fields, rules and procedures are used to limit errors by modifying or restricting human behavior through standards governing personnel qualifications, operating rules, and equipment design.

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[2] R. Curtis Graeber, National Aeronautics and Space Administration Ames Research Center, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings—OTA Workshop on Human Factors in Commercial Aviation Safety," unpublished typescript, May 28, 1987.

The first and basic step in minimizing error is employee selection—allowing into the system only those operators least likely to make mistakes. Airline pilots and air traffic controllers must meet prescribed health, age, and training requirements and pass written and operational tests of skills and knowledge. For the select group that survives the culling, continued quality is maintained through training and monitoring. Indeed, Federal regulations require the periodic testing of flight crewmembers to check results of training and operational experience, including flight proficiency and system knowledge. Pilots and controllers are also monitored through required periodic medical examinations, possibly including drug and alcohol testing in the near future.[3]

Potential errors can be forestalled by restricting human behavior. Careful control of the operating environment is the most wide-ranging of the methods for addressing human error in aviation. Federal regulations in this area address airline procedures such as pilot flight-time, emergency operations, and the use of checklists. Air traffic rules, including instrument approach and departure procedures, separation standards, and weather minimums set operational limits for users of the National Airspace System.

Training, monitoring, and operating rules are not enough, however, if the environment is poorly designed. "If human factors engineering is done properly at the conceptual and design phase, the cost is high, but paid only once. If training must compensate for poor design, the price is paid every day."[4] The Federal Government has the responsibility for setting appropriate standards for aircraft, airports, and navigation aids. Ideally, equipment is designed to reduce, not induce, human error.

To be optimally effective, these methods for controlling human behavior must be preceded by an understanding of the root causes of human error. However, this is an area still in need of much work. Most of the Federal Aviation Regulations (FARs) aimed at limiting human error are based primarily on past regulatory experience, not on scientific evidence. While previous experience is of course important, it is often insufficient or inappropriate in a changing environment. Recent technological developments, such as cockpit automation devices and displays, have outpaced the Federal Aviation Administration (FAA) regulatory process.

Compensating for Errors

An alternate approach to addressing human error assumes that errors will occur and then mitigates or nullifies them. Central to this method is an understanding of what errors occur; such information is provided by accident and incident investigations, which usually identify the human errors involved. Successful ways of compensating for known human errors entail changes to vehicles, equipment, or the environment. Modifying human behavior, even with respect to known types of human error, is a preventive measure as discussed in the previous section.

Monitoring of some type is often involved in negating errors. Warning devices are ubiquitous in jetliner cockpits and have proven invaluable. For example, the ground proximity warning system, required under FARs in 1975, has essentially ended controlled flight into terrain accidents by U.S. carriers. However, alerting systems or other devices may cause, as well as solve, problems. Excessive false alarms unnecessarily distract operators and may lead to the device being ignored or disabled. Consequently, a full system approach is required for all human error solutions.

Outside monitoring of airline flights is accomplished through the Federal air traffic control (ATC) system. Air traffic controllers detect gross navigation and guidance errors and provide useful information on weather and airport conditions to flight crews. En route controllers, in turn, are automatically monitored—ATC computers record the separation between aircraft under positive control and sound an alert if the distance falls below minimum standards.

On the technological forefront of human error control are "error-resistant" or "error-tolerant" systems based on automatic devices similar to those

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[3] Drug and alcohol testing is used currently at some air traffic control facilities.

[4] Earl L. Wiener, "Cockpit Automation," to be published in *Human Factors in Aviation,* E.L. Weiner and D.C. Nagel (eds.) (San Diego, CA: Academic Press, forthcoming), draft chapter, Mar. 23, 1987.

THR
TO/GA
10.9
DME 1.7
DH
52
FD
240
220
200
181
160
140
CRS---
MDA
299
400
200
100
80
200
1150
STD
180
128

Photo credit: Boeing Commercial Airplane Co.

Electronic cockpit displays indicate aircraft attitude, speed, heading, altitude, navigation, and warnings, such as windshear.

discussed earlier. The difference is that error-resistant systems have the additional capability of controlling and correcting the pilot's error. For example, fly-by-wire technology on the Airbus A-320 prevents the pilot from exceeding the operating envelope of the aircraft—on-board computers will not allow the aircraft to stall or overspeed, regardless of the deflection of the control stick. However, systems that seize control are themselves potential sources of error. Error-resistant systems should not take the place of error prevention methods, but can serve as the last line of defense against human errors.

Human Factors Data

Human error must be identified and understood before appropriate solutions can be proposed. Data are needed from both controlled laboratory experiments and actual flight operations.

One valuable source of field data is post-accident analyses. However, such data may result in only limited understanding of the cause of the human error, especially if no flight crewmembers survive or information is restricted because of litigation concerns. Another data source is reports from crewmembers concerning aviation incidents. The Aviation Safety Reporting System (ASRS), administered by the National Aeronautics and Space Administration (NASA) at the Ames Research Center and funded by FAA, collects such reports and FAA guarantees anonymity and immunity from enforcement actions to reporters.[5] ASRS was designed to gather analytical data, with emphasis on human behavior. To assure participants that the data would be kept confidential, NASA was chosen to host the system, since it is not a regulatory or enforcement agency and had experience in human factors research. The program has proven valuable, supporting numerous studies by government, industry, and academia.

ASRS has become so popular with the U.S. aviation community that the average number of reports has increased from fewer than 800 per month in 1985 to over 1,700 per month in 1987. Until recently, the ASRS budget had not grown, forcing NASA to divert resources to data processing at the expense of data analysis and special studies.[6] For fiscal year 1988, FAA increased ASRS funding from $1.5 million to $1.9 million.

While industry and academia have conducted research in selected areas, the only consistent Federal human factors research effort for civilian flight crews has been maintained by the Aerospace Human Factors Research Division at NASA Ames Research Center. During the past 10 years, research has emphasized automation, communications, cockpit resource management, use of simulators, visual perception, human sleep needs, and pilot fatigue. In recent years, FAA has provided only limited support for NASA's human factors research and development. However, a 5-year interagency agreement was initiated recently and NASA's Office of Aeronautics and Space Technology has obligated fiscal year 1989 funds for human factors research on aviation safety and automation at Ames and Langley Research Centers.

FAA has supported selected cockpit research projects both by NASA and private contractors, and has conducted ATC human factors studies at the Civil Aeromedical Institute (CAMI), the FAA Technical Center, and with private contractors. CAMI, under the guidance of the Associate Administrator for Human Resource Management and the Office of Aviation Medicine, performs research and evaluation on the influence of sleep patterns, alcohol, noise, drugs, and age on performance; stress management techniques; field performance measurement and evaluation (including operational errors); supervisor/manager selection and training; and job/task analysis for better selection criteria.

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[5] For more details on the anonymity and immunity provisions of Aviation Safety Reporting System, see ch. 4.

[6] William Reynard, chief, Aviation Safety Reporting System, personal communication, Jan. 25, 1988.

Human performance data from actual operations are difficult to obtain. Flight data recorders, cockpit voice recorders, or video cameras could be used to collect such data. However, pilots and controllers are sensitive to being monitored and are concerned about the possible misuse of data, and few objective measurement criteria have been established. While laboratory research provides insight into the effects of automation, aeromedical stressors, and crew interactions on operational safety, these findings must ultimately by verified in the field. NASA Ames, in conjunction with the Air Line Pilots Association (ALPA), and some air carriers, has collected some field data. Additionally, a number of university research projects, on topics such as cockpit resource management or automation in modern cockpits, are based on information gathered directly by human factors specialists riding in jetliner cockpits.

INDUSTRY AND FEDERAL ROLES IN HUMAN FACTORS

Growing Concerns

Human factors problems in commercial aviation are not new: standards for personnel age, health, training, and work shifts, along with aircraft design and operation requirements and the ATC system are all directed at preventing or minimizing human errors. However, new technologies, Federal regulations and advisories, and industry and union initiatives have been more effective in preventing other types of accidents, and the rate of pilot error-involved accidents has not declined in the past decade. Additionally, rapid changes in airline operating and hiring practices and developments in cockpit technology have outstripped the FAA regulatory process. Most of the regulations dealing with human factors are not based on modern scientific findings, and few have been revised or reassessed in recent years. These problems are presented in detail below.

Pilot Selection and Training

Rapid expansion of commercial airlines during the past decade has created shortages in the supply of qualified pilots. The situation has been exacerbated by increased retention of military pilots who were once the mainstay of the airlines (see chapter 5) and declines in general aviation pilot training. For example, the number of new private pilot certificates issued annually dropped from over 58,000 in 1978 to fewer than 35,000 in 1986.[7] Additionally, ALPA statistics indicate that the number of airline pilots reaching retirement age per year will increase until at least 1999. The large commercial carriers are increasingly recruiting pilots from the smaller Part 121 regional and Part 135 commuter airlines, resulting in rapid turnovers in the regionals' pilot work force, greater than 100 percent per year for some. The training burden on these smaller carriers is enormous. For example, in 1987, the flight crew training costs at one regional airline exceeded the pilots' salaries.[8] Moreover, large and small carriers alike have been forced to lower their selection criteria for new hires (see chapter 5). FAA is just beginning to address FARs regarding training, experience, age, or health requirements.

Age and Health.—Given the changes in the operating environment, the shortages in the pilot supply, and advances in medical understanding and technology, the age and health standards for air carrier pilots might need refocusing. The rule requiring mandatory retirement at age 60 for air carrier pilots is one example, since from a medical perspective, age is a coarse predictor of human capabilities.

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[7] U.S. Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation* (Washington, DC: published annually).

[8] J.A. McIntyre, Air Line Pilots Association, personal communications, Mar. 3, 1988.

FAA statistics show clearly that general aviation pilots 60 to 69 years old have accidents at twice the rate of pilots 50 to 59 years of age.[9] However, data are not available on what percentage of retired airline pilots continue to meet all the physical and mental competency requirements for commercial transport pilots. Questions that need examination include: what types of medical testing would be necessary to allow these pilots to remain in the work force? What criteria should be measured and what is the appropriate frequency of examinations?

While drug and alcohol testing has been widely discussed and might be required of transportation workers by the Federal Government, other forms of on-site monitoring such as testing pilot fatigue over long flights have rarely been addressed. The capability exists or is being developed for real-time monitoring of certain physical and mental parameters of operator health. The potential of these methods for improving operational safety is unknown, although it could be substantial in the case of drowsiness, fatigue, or illness. However, the sensitive issue of privacy and other concerns must be considered and balanced against safety gains.

Experience.—FAR pilot qualifications have been considered by many to be too low. For example, a jetliner copilot can meet all requirements with only 250 total hours of flight-time.[10] Until recently, this has not been a concern since the airlines have traditionally set their own standards much higher than the Federal requirements. However, while still well above FAR minimums, the average qualifications (total flight-time as well as other indicators of experience) of new pilots are decreasing (see chapter 5).

The rapid expansion of air carriers has also resulted in junior cockpit members advancing to captain without the "seasoning" that was common in the past. While pilots formerly spent several years as flight engineers and then several more as co-pilots before moving into the left seat, promotion to captain with only months of experience is increasingly common at some airlines.[11] For example, at one mid-sized commuter, 45 out of 70 captains were in their first year of employment.[12] Additionally, the replacement of three-person crew aircraft with two-person crew transports means that newly hired crew members increasingly receive their initial jetliner experience as co-pilots.[13]

Total time, whether hours in a logbook or years in a crew position, does not give the complete picture of pilot experience, skill, or quality of training. For example, full-motion flight simulators or advanced training devices enable a pilot to meet with more emergencies and unusual situations in a 4-hour training session than he may experience on the line during a 20-year career. However, few measures of pilot ability other than flight-time have been collected broadly and consistently. Alternative measures or tests of skill and experience could prove useful.

Airline Training Programs.—FARs give wide latitude to carriers with respect to training programs, and flight simulators and computer systems add dimensions to the training process. Modern cockpit technology has shifted the primary tasks of the pilots from physically flying the aircraft to managing it. The adequacy of current training programs and standards have been questioned; FAA has stated that the entire pilot training and rating system needs reexamining and has initiated a program to do so.[14] Additionally, the importance of early training and conditioning and their effect on future pilot performance have not been fully considered in commercial aviation,[15] but are receiving increased attention by several airlines.

Some airlines have implemented training programs, called cockpit resource management (CRM) training, which focus on flight crew management and communication. Line oriented flight training (LOFT), full mission crew coordination training conducted in flight simulators, is also considered valuable by a number of airlines and military aviation groups worldwide. For example, United Airlines

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[9] Anthony I. Broderick, associate administrator for Aviation Standards, Federal Aviation Administration, personal communication, Mar. 31, 1988.

[10] 14 CFR 121.437 (Jan. 1, 1987).

[11] Progression to captain at Part 121 air carriers currently takes several years on average. John O'Brien, director of Engineering and Air Safety, Air Line Pilots Association, personal communication, Feb. 29, 1988.

[12] McIntyre, op. cit., footnote 8.

[13] However, the flight engineer position might not be effective as a training base, as many flight engineers have had difficulty transitioning to a pilot position. Delmar M. Fadden, Boeing Commercial Airplane Co., personal communication, Mar. 1, 1988.

[14] David Hughes, "Four-Year Pilot Hiring Boom Creates Problems for Carriers," *Aviation Week & Space Technology*, Oct. 5, 1987, p. 97.

[15] Frank Monastero, aviation consultant, T.M. Monitor Corp., personal communication, Feb. 23, 1988.

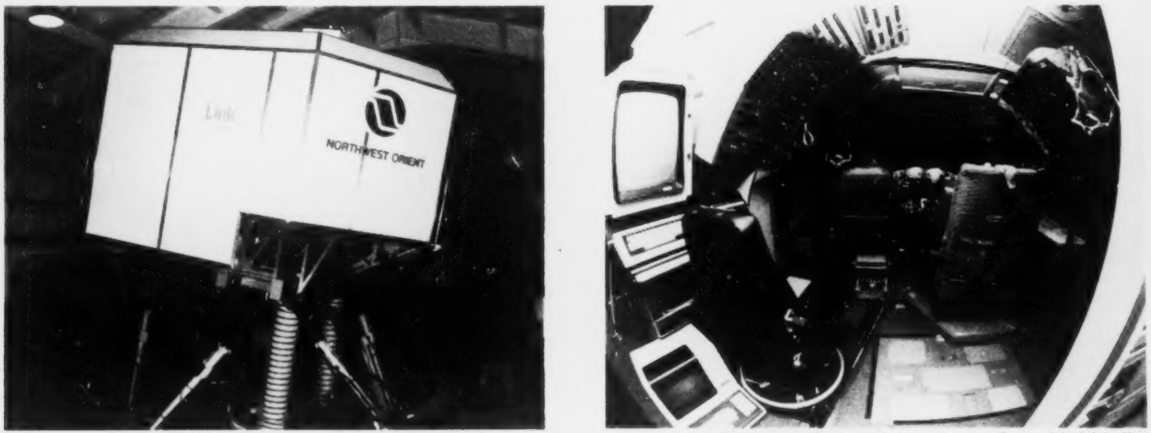

Photo credit: The Singer Co.

Photo credit: National Aeronautics and Space Administration

Full-motion flight simulators re-create jetliner operations so realistically that pilots can be trained in them and certified without flying the actual aircraft.

conducts an annual 3-day training and proficiency checking program using CRM and LOFT. FAA has supported this type of training by granting waivers to United and Pan Am, allowing them to reduce their cockpit crew recurrent training and proficiency checks to one per year instead of the normal 6-month check.[16] There are yet no data proving that CRM is effective, and no regulations mandating CRM.[17] However, a Joint Government/Industry Task Force on Flight Crew Performance, formed by FAA in August 1987, has drafted an advisory circular on CRM/LOFT. Research is also underway by the University of Texas at Austin to evaluate the effects of CRM/LOFT on pilots at a number of airlines and military squadrons.[18]

Type Ratings.—Unlike automobile or truck drivers, airline pilots must be licensed for a specific vehicle model. A pilot licensed to fly a B-737 is allowed to fly any version or derivative of the B-737, provided he is trained on their differences, but cannot fly a B-727 unless he first receives a full course of instruction, passes a written and flight examination, and is granted a "type rating" for the B-727. Type, as used with respect to pilot ratings, ". . . means a specific make and model of aircraft, including modifications thereto that do not change its handling or flight characteristics. . . ."[19]

Common type ratings of derivative aircraft offer economic advantages to airlines and manufacturers alike. It is much less expensive for a manufacturer to obtain FAA certification for a derivative than for a new type, since only modifications need close scrutiny. One benefit is that manufacturers are able to offer aircraft innovations to the airlines without developing totally new aircraft. For example, new, technologically-advanced B-737s and DC-9s, (MD-80 series) are covered by type ratings issued in the 1960s (supplemented by pilot training on the modifications).

The manufacturing emphasis on derivatives reflects their popularity with airline management. Fleet expansion by derivatives instead of different types usually permits lower crew training costs: less time is required to train pilots in multiple models and new simulators are not necessary. Single type fleets also enable greater flexibility in crew scheduling. The importance of type considerations is reflected in the fact that the only new aircraft types introduced by a U.S. manufacturer in the 1980s are the B-757 and B-767, and they have a common pilot type rating.

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[16] Richard S. Jensen, Ohio State University, "Feasibility Study for the Assessment of Cockpit Resource Management Training," prepared for U.S. Department of Transportation, February 1987, p. 10; and O'Brien, op. cit., footnote 11.

[17] Ed Cook, "The Regulatory Horizon," *Cockpit Resource Management Training: Proceedings of the NASA/MAC Workshop*, NASA Conference Publication 2455, Harry W. Orlady and H. Clayton Foushee (eds.) (Moffett Field, CA: National Aeronautics and Space Administration, Ames Research Center, 1987), p. 178.

[18] John A. Wilhelm, The University of Texas at Austin, personnel communication, Feb. 9, 1988.

[19] 14 CFR 1.1 (Jan. 1, 1987).

The safety and economic issues at stake over type ratings have caused considerable controversy. FAA certificated the DC9-80 (MD-80) with a two-person crew, instead of the customary three-person crew, in August 1980. However, this caused such contention that a Presidential Task Force had to be established. The report of the Task Force affirmed the FAA decision. The main point of discussion among the manufacturers, FAA, and the pilots unions still centers around when two different aircraft versions are the same type. While handling and flight characteristics are the only type criteria in current regulations, cockpit changes are a substantial human factors concern. However, cockpit certification does not receive the level of quantitative analysis by FAA as do other aircraft component certifications. Effectively, the cognitive aspects are considered by using subjective assessments of flight crew workload based on the judgment of test pilots who rate a new cockpit as "better" or "worse" than a comparable one. Quantitative engineering evaluations, such as the performance criteria used for engine designs, are not feasible for many aspects of modern cockpits.[20]

Currently, FAA is developing new standards for determining separate type ratings. Cockpit design and pilot training will be prime considerations in an FAA advisory circular, which is to be issued for public comment in 1988.

Advanced Cockpit Technology

Automation.—"Automation," or assigning to machines or computers physical or mental tasks previously performed by the crew, is a frequently cited means of reducing human error. While totally eliminating humans from the operational loop is not yet feasible nor necessarily desirable, partial replacement is becoming increasingly common. Theoretically, automation minimizes or prevents operational human errors by reducing the physical or mental workload of the human operator, or by eliminating the human from an operational control loop. Used appropriately, automation is a valuable tool; the autopilot, a flight-path control device, is one such item.

Automated devices can provide for more efficient and precise flight operations, but they also require monitoring and proper setting, areas where people can and do make errors. For example, digital navigation equipment is susceptible to keyboard entry or "finger errors." Such errors can easily go unnoticed by the crew; it is believed that KAL 007 flew off course because of a keyboard error.[21] A broader

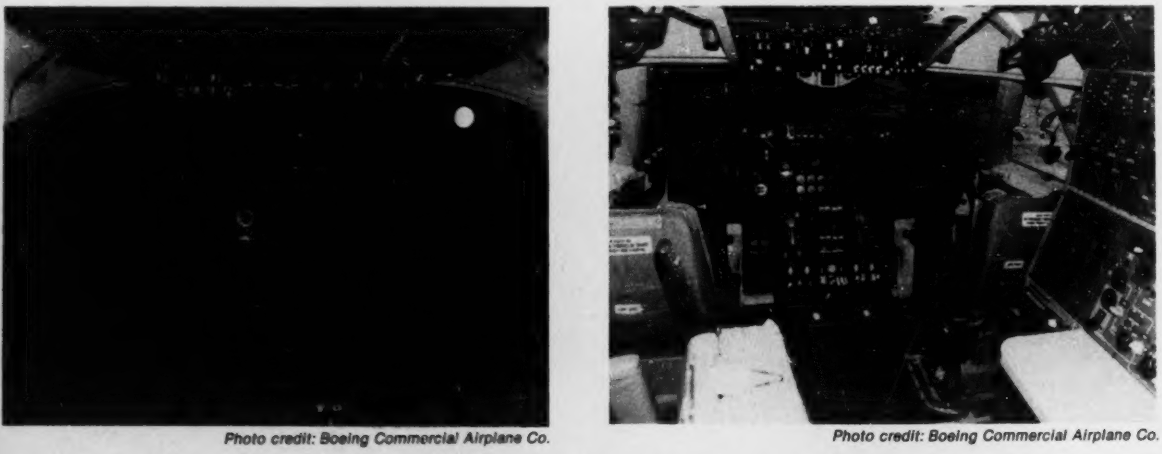

Photo credit: Boeing Commercial Airplane Co.

Photo credit: Boeing Commercial Airplane Co.

In modern cockpit designs (left), electronic displays replace many electro/mechanical instruments (right), as shown in these photographs of Boeing 747 cockpits.

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[20] U.S. Department of Transportation, Federal Aviation Administration, *Aviation Behavioral Technology Program: Cockpit Human Factors Research Plan* (Washington, DC: Jan. 15, 1985), pp. 20-21.

[21] Earl L. Wiener, "Beyond the Sterile Cockpit," *Human Factors*, vol. 27, No. 1, February 1985, pp. 75-90.

problem is that automatic devices are often installed one item at a time, especially in older aircraft, without the consideration of the overall pilot-cockpit system.

There are no FARs relating cockpit automation to human performance, and no real expertise within FAA, to address this issue. For example, the advanced cockpit electronic systems on the Boeing 757 and 767 airplanes required an "equivalent safety" deviation from current regulations to be certified.[22] Automatic devices for the cockpit, which have subtle effects on human performance, are treated the same as other pieces of hardware in the regulations. Human error hazard analyses are not required in the design, test, or certification stages.[23] Some basic standards for cockpit design are included in FARs, but they do not address technological developments of the past decade such as CRT displays and flight management systems. For example, although the use of color has increased in modern cockpit devices, FAA has set standards only for warning, caution, and advisory lights. There are no rules governing other uses.

Participants at OTA's Workshop on Human Factors in Commercial Aviation Safety stressed that the use of automation will only increase, and most believed that FAA is unprepared to handle current and future automation issues. The role of the human in an increasingly automated environment needs to be studied and bases established for setting standards. ATC is also likely to be increasingly automated. Box 6-A describes automation programs now being planned.

Air-to-Ground Communication.—Verbal communication remains the weakest link in the modern aviation system; over 70 percent of the reports to ASRS involve some type of oral communication problem related to the operation of an aircraft.[24] Technologies, such as airport traffic lights or data link, have been available for years to circumvent some of the problems inherent in ATC stemming from verbal information transfer. (For more information on communications technologies, see chapter 7.) The ground collision between two B-747 aircraft in Tenerife in 1977, resulting in the greatest loss of life in an aviation accident, occurred because of a communication error.

Box 6-A.—Air Traffic Control Automation

One aspect of the National Airspace System Plan, the Advanced Enroute Automation System (AERA), could bring sweeping job changes for air traffic controllers through automation. AERA is software to be introduced in three stages as part of the Advanced Automation System (AAS), the Federal Aviation Administration's (FAA) planned upgrade to the entire air traffic control system (see chapter 7). The effectiveness of automation in accomplishing job tasks and the consequences of individual controller performance differences is being studied at the Civil Aeromedical Institute. FAA plans to study controller selection and training requirements for AERA. An FAA contractor has built and installed prototypes of portions of AERA algorithms in a simulation laboratory. Used for subjective evaluations of controller interactions with automation, this initial test system does not have enough realism for quantitative efficiency measurements. Controllers taking part in the testing provide their views on the utility of the automated aids and the nature of inter-controller coordination in the advanced environment. FAA plans to quantify the benefits of AERA in real-time evaluations once the AAS contractor has installed hardware at the FAA Technical Center (scheduled for 1994). At present, there are no firm plans for AERA hazard analyses, and data gathering for the real-time evaluations has not been articulated.

One potential problem with ATC by data link is that the loss of the "party line" effect (hearing the instructions to other pilots) would remove an important source of information for pilots about the ATC environment. However, the party line is also a source of errors by pilots who act on instructions directed to other aircraft, or who misunderstand instructions that differ from what they anticipated by listening to the party line. Switching ATC communication from hearing to visual also can increase pilot workload under some conditions.[25] Further study is necessary to define the optimum uses of visual and voice communications.

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[22] Delmar M. Fadden, Boeing Commercial Airplane Co., Office of Technology Assessment, op. cit., footnote 2.

[23] C.O. Miller, aviation consultant, personal communication, Feb. 13, 1988.

[24] Ralph L. Grayson and Charles E. Billings, "Information Transfer Between Air Traffic Control and Aircraft: Communication Problems in Flight Operations," NASA Technical Paper 1875, September 1981, pp. 47-61.

[25] Fadden, personal communication, op. cit., footnote 22.

Management Practices

The judgment and skill of the pilots, mechanics, air traffic controllers, and other key people in the aviation system are influenced, to varying degrees, by management decisions. While many aspects of human behavior fall outside the sphere of management and are an inescapable part of a highly demanding and complex system such as commercial aviation, some depend on how the system is organized and operated. For example, airline management practices regarding pilot selection and training, as well as aircraft design, provide the underpinnings of pilot performance. A considerable amount of public debate has focused on airline operational pressures and employee stress.

The terms "stress" and "fatigue" are commonly used in everyday discourse, but with widely varying meanings and contexts. A "stress factor" is a physiological or psychological pressure or force acting on a person which compels him to act or react, physically, cognitively, or emotionally. Examples of stress factors in aviation range from noise, vibration, and glare in the cockpit, to anxiety over weather and traffic conditions, to anger, frustration, and other emotions. Chronic stress degrades performance and decisionmaking, and the overall effect of multiple stresses is cumulative. Another product of cumulative stress is fatigue, which can also result from inadequate rest, too much cognitive activity, increased physical labor, or disruption of physiological rhythms.[26]

Stress is difficult to measure in an operating environment, and little clinical evidence is available on the cause-and-effect relationship of stress, especially psychological or social stress,[27] with performance ability. Concern about stress is not new: workload and duty shift conflicts, ATC and weather delays, and labor/management problems are traditional occupational stresses in commercial aviation. However, developments since deregulation have exacerbated many of the environmental stress factors. Record amounts of commercial traffic, increased use of hub and spoke systems, crowded airspace and airport ground facilities, and the resulting schedule pressures have taken a toll on pilot, mechanic, and air traffic controller morale and, in some cases, performance.[28]

Schedule pressure is a function of the whole airspace system as well as of individual airline practices. Management attitudes, especially labor/management relations, determine how schedule pressure is interpreted in the cockpit and on the flight line. Additionally, airline mergers frequently have resulted in divisive seniority and pay scale arguments among management and the merging work forces. Cockpit crews comprised of pilots holding opposite views on unresolved merger issues bring additional stress to commercial flight operations.

Virginia Polytechnic Institute and State University, under contract to ALPA, is studying stress and its effects on airline pilots. One purpose of the research is to compare pilot populations from different carriers and to determine differences based on established psychological measures of stress. Surveys were conducted in July 1986, at one "unstable" and two "stable" major airlines. For this survey, the unstable airline was one that was sold, merged, or taken over in a 12-month period, had a net loss for the last two earning periods, and had employee wage/work rules concessions in the last contract. The pilots from the unstable carrier, with a long history of labor-management problems and its recent acquisition by another carrier, presented a distinctly different stress profile than the other pilots. While 55 percent of the stable airline pilots exhibited none of the high stress measures (such as low self-esteem, depression, and physiological indications), only 10 percent of the pilots from the unstable carrier showed no high stress. Additionally, 30 percent of pilots from the unstable airline indicated high stress on 4 or more stress measures as compared with only 5 percent of the pilots from the other airline. The stress profiles were so dissimilar among the airlines that 90 percent of the pilots who expressed high stress symptoms could be correctly identified by carrier affiliation.[29]

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[26] H. Clayton Foushee, Aerospace Human Factors Division, National Aeronautics and Space Administration—Ames Research Center, in *Influence of Training, Operational and Maintenance Practices on Flight Safety*, op. cit., footnote 1, pp. 149-164.

[27] Cary L. Cooper and Stephen Sloan, "Occupational and Psychosocial Stress Among Commercial Aviation Pilots," *Journal of Occupational Medicine*, vol. 27, No. 8, August 1985, pp. 570-576.

[28] OTA, primary research, 1987.

[29] Linda F. Little, Virginia Polytechnic Institute, testimony before U.S. Congress, House Committee on Economic Stabilization, Subcommittee on Banking, Finance and Urban Affairs, May 12, 1987, and Linda F. Little, Virginia Polytechnic Institute, "The Pilot Research Project: 1987 Data," unpublished data.

Airline operating safety is based upon well-rested and alert flight crews. An analysis of ASRS data revealed that about 4 percent of crewmember error reports were directly associated with fatigue, and 21 percent mentioned factors directly or indirectly related to fatigue.[30] NASA-Ames currently has a comprehensive program underway to examine fatigue-related problems in short-haul and long-haul commercial and military flight operations. Already completed, the short-haul phase of the study examined flight crews before and after they had completed a 3-day, "high-density" trip. The findings illustrate the complexities involved in analyzing human performance. The post-duty crews, by all measures, were more fatigued than the pre-duty crews. However, the more tired post-duty crews performed significantly better and made fewer errors during the laboratory simulator sessions. The study concluded that flight crew communication and coordination patterns were largely responsible for the performance differences. Recent operating experience and crew familiarity can override fatigue factors in some short-haul operations.[31]

FARs, ostensibly addressing crewmember fatigue,[32] are silent on items such as pilot duty-time, considered crucial in other countries. Some experts believe that duty-time, the time spent in-flight, and on the ground for preflight, postflight, and between flight stages, is a superior measure for evaluating fatigue in air transport operations.[33] An analysis of the aviation regulations for nine industrial nations shows that only the United States and France do not explicitly consider pilot duty-time.[34] FAR work rules also do not consider the number of takeoffs and landings performed, the number of time zones crossed, and whether crew rest immediately precedes flight duty, issues considered important in many other countries.[35]

Federal Responsibilities

Throughout the history of aviation, safety improvements have come primarily from technological developments, such as reliability and performance increases in aircraft, navigation devices, weather forecasting, and ATC. FARs emphasize, with more precise standards, the technical aspects governing aircraft operations and certification rather than the human factors considerations. Although some human factors-related data collection, analysis, and research are supported and conducted by the Federal Government, FAA has requested little that can be applied to regulatory decisionmaking. FAA does not have a centralized and systematic approach to improving flight crew performance.[36] DOT (primarily FAA), NTSB, and NASA are the Federal agencies involved in civil aviation human factors.

FAA

FAA, and its predecessor the Civil Aeronautics Authority, have addressed numerous human behavior issues through guidelines and oversight. Many Federal regulations and advisories reflect efforts to prevent human error, although few of these rules are based on proven scientific principles. Time-tested procedures and regulatory experience are valuable background data for setting human factors standards, but as discussed in the previous sections, technological and managerial developments in commercial aviation have outpaced FAA's regulatory capacity. Pilot selection and training rules have not been substantially revised in decades, and cockpit design requirements ignore much of the current human factors knowledge.

FAA, recognizing the importance of human factors in aviation safety, has sponsored several workshops, conferences, and studies on human performance in aviation. However, none of these efforts has resulted in major policies, programs, or rules. The President's Task Force on Aircraft Crew Complement recommended in 1981 that FAA support and expand a number of human factors-related research areas.[37] By 1985, FAA had developed a Human Factors Research Plan comprised of 23 research projects to address a number of cockpit- and pilot-related problems.[38] Because of austere budgets and the 2-year cycle for initiating new projects, few of its projects were initially funded. However, by 1987, 18 of the 23 projects had received some funding from FAA or other Federal agencies and 1 was completed. Additionally, the Transportation Systems Center was tasked under a project agreement with FAA to update the plan and publish a revision.

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[30] R. Curtis Graeber, "Sleep and Fatigue in Short-Haul Flight Operations: A Field Study," Flight Safety Foundation Proceedings, op. cit., footnote 1, pp. 142-148.

[31] Foushee, op. cit., footnote 26, pp. 149-164.

[32] 50 *Federal Register* 29306 (July 18, 1985).

[33] Hans M. Wegmann et al., "Flight, Flight Duty, and Rest Times: A Comparison Between the Regulations of the Different Countries," *Aviation, Space, and Environmental Medicine*, March 1983, pp. 212-217.

[34] Ibid.

[35] The Federal Aviation Regulations (14 CFR 121.47) address duty time by exception: the minimum rest period a crewmember must have during any consecutive 24-hour period is 8 hours, implying an allowable duty period of up to 16 hours.

[36] Federal Aviation Administration, op. cit., footnote 20, p. 6.

[37] The President's Task Force on Aircraft Crew Complement, "Report of the President's Task Force on Aircraft Crew Complement," unpublished manuscript, July 2, 1981, pp. 8-12.

However, the underlying reasons for limited past FAA action on human factors still exist; FAA has never devoted the resources necessary to deal objectively with human factors issues. The Office of Flight Standards, responsible for establishing and enforcing air carrier operating regulations, has one person assigned as a human factors coordinator but no separate organizational element with human factors responsibility.

Regulatory policy must be supported as well by documented data and research findings. As discussed in chapter 4, FAA's data collection and analysis efforts could be revised to provide support for human factors research. Although FAA conducts and supports research projects on human factors in ATC, it has only recently devoted staff or budget for efforts in cockpit human factors. While a regulatory agency such as FAA need not necessarily undertake a substantial amount of fundamental research in any technical field, including human factors, it must have access to up-to-date scientific and technical research results so as to exercise timely judgment on technical issues. To do so, FAA needs trained staff to define and manage FAA-supported research efforts, to analyze and interpret findings, and to review and promulgate regulations.

Staff shortages are compounded by coordination difficulties inherent in the FAA management structure. Human factors responsibilities are spread piecemeal throughout FAA and the Department of Transportation. While cockpit-related research projects are managed under the Associate Administrator for Development and Logistics, primarily by the Program Engineering and Maintenance Service, the impetus must formally be provided by the Associate Administrator for Aviation Standards (AVS). For example, FAA's Transport Aircraft Certification Division, located in Seattle and responsible for approving commercial transport cockpit designs, cannot task the Program Engineering and Maintenance Service directly, but must pass all requests through AVS.

The Office of Aviation Medicine and its Civil Aeromedical Institute (CAMI) provide data upon which AVS can base regulations and advisories. However, most of the human behavioral studies at CAMI's Aviation Psychology Laboratory are directed toward ATC.[39] The effectiveness of another regulatory research source in human factors for FAA, the Transportation Systems Center, is diminished by the bureaucratic entanglements that result with inter-administration projects.

AVS collects and maintains field data, such as accident and incident reports and air carrier inspection findings, that could support human factors rulemaking. However, these data management efforts have provided few safety analyses. Additionally, the Office of Aviation Safety, located in yet another division and responsible for broad safety studies, has undertaken no recent human factors analyses.

NTSB

Human factors receive a great deal of emphasis in NTSB investigations of major accidents, the resulting determinations of probable cause, and recommendations for future accident prevention. NTSB has a separate Human Performance Division within its Bureau of Technology and usually includes a human factors specialist on each major accident investigation team. Report forms, interviews, and analytical techniques are designed to elicit detailed information on the performance of the people involved in the mishap and the environmental and operating conditions that were present.

NTSB accident database management and analyses are critically important, for they provide the only valid statistical safety trends currently available to the Federal Government (see chapter 4). While lessons can be learned from individual accidents, the greatest understanding comes from analyses of clusters of accidents. For example, the frequent occurrence of flight crew coordination problems in accidents has resulted in numerous NTSB recommendations urging the use of cockpit resource management training.[40]

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[38] Federal Aviation Administration, op. cit., footnote 20.

[39] Ibid, p. 112.

NTSB analyses are sometimes published in detailed special studies, covering such topics as runway incursions, airport certification and operations, and commuter airline safety. However, NTSB has not undertaken a comprehensive analysis, and has published no special studies on human factors in aviation.

NASA

NASA has traditionally provided a substantial amount of fundamental aviation research. For human factors in civil aviation, NASA contributes a major share of research, supplemented only by applied research programs in industry and basic research at a handful of universities. NASA is in a unique position which enhances its human factors research efforts. While maintaining close working relationships with FAA, NTSB, the military, and the commercial aviation industry, nonregulatory NASA is viewed as an impartial party. This gives NASA access to sensitive data unavailable to other Federal groups.

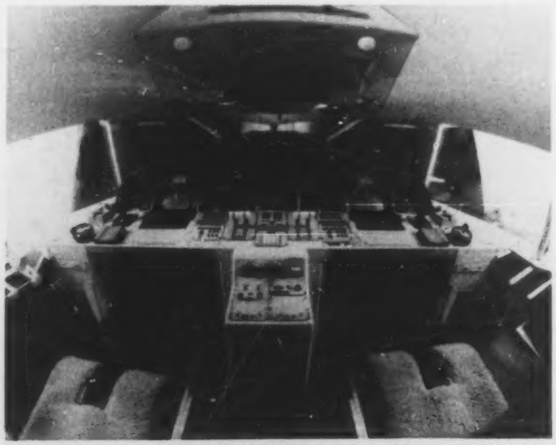

Photo credit: National Aeronautics and Space Administration

Researchers investigate the effects of future cockpit technology on human performance with the Advanced Concepts Flight Simulator at NASA-Ames Research Center.

Two research centers within NASA, Ames in California and Langley in Virginia, are responsible for most of the human factors work. Generally, NASA-Langley investigates the physical aspects of human factors, while NASA-Ames studies the psychological elements. Physiological measures of pilot workload and advanced cockpit displays are among the topics addressed at Langley. The operational implications of human factors research—cockpit resource management, information transfer, sleep cycle and fatigue, and the effects of advanced automation on flight crew performance—are important fields of study at NASA-Ames. For example, LOFT was developed from the use of full-mission simulation as a research tool at Ames.

NASA-Ames also administers the Aviation Safety Reporting System, the only broad source of human factors field data other than NTSB investigations available to the Federal Government. However, effective use of ASRS data has been hampered in recent years by level funding in the face of increasing reports, resulting in resources being diverted from analysis to processing. NASA-Ames increasingly has become the human factors information clearinghouse.[41] While all databases have limitations, ASRS analyses could provide information unavailable to FAA from other sources, such as the influence of new technologies or airline management practices on human performance.

Industry Responsibilities

Airlines and aircraft manufacturers regard safety seriously, giving clearly indicated safety problems quick and thorough attention. Understandably, however, industry rarely undertakes voluntary safety-oriented improvements unless the link between the improvement and safety is clearly established. FAA, as the regulatory agency, must shoulder primary responsibility for the absence of human factors standards.

The lack of objective cockpit certification standards is a case that illustrates how human factors-related decisions are made (or not made). According to one NASA official, most of NASA's fundamental civil aviation research efforts have focused on areas such as aerodynamics, propulsion, avionics, and materials. Less emphasis is placed on human factors, since aircraft manufacturers do not consider human factors to be a technology that controls whether an aircraft design is feasible or not. The manufacturers cite airline concerns with reducing operating costs through better fuel efficiency and lower maintenance expense. The airlines do not usually question FAA-approved cockpit designs or other FAA-certified components, such as engines. FAA completes the circle, stating that no data are available, such as research findings from NASA, to justify establishing cockpit certification standards.[42]

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[40] John K. Lauber, National Transportation Safety Board, "Cockpit Resource Management: Background and Overview," *Cockpit Resource Management Training*, op. cit., footnote 17, p. 12.

[41] Graeber, op. cit., footnote 2.

This is not to say that the private sector has not done its best to ensure that cockpit designs are safe. Through Society of Automotive Engineers committees, industry groups (partially funded by FAA and other Federal agencies) have established some cockpit design standards. Compliance with these voluntary standards has traditionally ensured FAA approval of designs.[43]

Economic considerations play a major role in cockpit layout decisions. For example, a number of recent advances in cockpit technology have been driven by airline cost savings. Two-person v. three-person crew complements reduce salary expenses; common type ratings save on training and scheduling costs; automation allows more efficient and precise flight path control; and solid-state avionics have lower maintenance costs than electro/mechanical devices. "While no reputable manufacturer knowingly compromises safety for short-term cost savings, clear, comprehensive Federal requirements are important in assuring that no actual compromise in safety occurs."[44]

Moreover, OTA finds that a systems approach is needed for cockpit certification. While FAA can adequately ensure that a given cockpit design is not unsafe, the cross-effects of pilots flying in multiple cockpit versions has not been sufficiently addressed. The effects of standardization in cockpit design on pilot performance need to be more fully examined and documented. Additionally, certification approval of vastly different cockpit designs has been criticized by at least one U.S. aircraft manufacturer. Boeing based cockpit display designs on its research into color visibility in electronic displays. The research findings conflict directly with the color standards used for Airbus cockpits, yet FAA approved both standards.[45]

The airlines are left with the responsibility of accommodating differing cockpits. One option, purchasing uniform fleets, is rarely feasible. Different aircraft requirements for different markets, as well as mergers and acquisitions, have left airlines with diverse fleets. Training is the approach used by the airlines and approved by FAA to prepare pilots for these different aircraft. Provided he or she has the required training, a pilot can fly any number of different aircraft in revenue service, even in a single day. However, in present airline operations, very few pilots need to stay current in two or more aircraft that have separate type ratings.[46]

Innovations in training are readily accepted by airlines, provided that the costs are not prohibitive. Advanced simulators allow greater flexibility and safety and have become the preferred mode in training, and they also offer substantial cost savings. Cockpit resource management training has been adopted by a number of airlines.

Airline management has the responsibility of addressing the human factors problems that have arisen due to operating practices and management attitudes. Some airlines have employee assistance and counseling programs and provide for good communication in both directions along the chain of command. Others have conducted internal safety audits. The recent spate of mergers provides a laboratory for comparing the effectiveness of differing airline management practices. A number of U.S. airlines provide open access for NASA-Ames research.[47]

TWA established internal safety teams and conducted audits in 1976, 1980, and 1986. The teams, composed of line pilots and management personnel, were granted immunity from revealing information sources, and top management gave them permission to examine all areas of flight safety. As an outcome of the audits, TWA has instituted periodic labor-management safety meetings. The sterile cockpit concept,[48] now a Federal regulation,[49] came out of these TWA meetings. Additionally, TWA has instituted a nonpunitive program for monitoring flight data recorder approach information. Notably, while the program receives the support of TWA's pilots, in-flight monitoring is anathema to pilots at most other carriers. Airlines that carry out safety audits may find the process as important as the product. Employee perception that management recognizes and is addressing a problem can play a large part in the resolution of the problem.[50]

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[42] Susan Norman, National Aeronautics and Space Administration, Ames Research Center, personal communication, Nov. 19, 1987.

[43] Fadden, op. cit., footnote 22.

[44] Delmar M. Fadden, personal communication, Mar. 1, 1988.

[45] Fadden, op. cit., footnote 22.

[46] Ibid.

[47] R. Curtis Graeber, National Aeronautics and Space Administration Ames Research Center, personal communication, Mar. 2, 1988.

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[48] During critical phases of flight (below 10,000 feet and all ground operations), crewmembers can perform only those duties required for the safe operation of the aircraft. For example, extraneous conversation, including pointing out sights of interest to passengers, is prohibited.

[49] 14 CFR 121.542 (Jan. 1, 1987).

[50] J.A. McIntyre, Airline Pilots Association, in *Influence of Training, Operational and Maintenance Practices on Flight Safety*, op. cit., footnote 1, pp. 118-124; and J.A. McIntyre, in Office of Technology Assessment, op. cit., footnote 2.

Labor's Role

Organized labor has an important role in the resolution of management-related human factors problems, and union contracts or initiatives often address issues not covered by Federal policy. For example, some pilot contracts establish duty-time limits, since FARs are not explicit in this area, and while FARs permit Part 121 pilots to fly 100 hours per month, few actually do.[51] Additionally, labor organizations provide publications, training programs, counseling sessions, and communication channels to management for member employees. Unions also support independent studies and research efforts, such as ALPA's stress survey, and ALPA has safety councils at each of its member domiciles.[52] For further discussion of labor-related issues, see chapter 2.

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[51] OTA primary research, 1987.

[52] Ibid.

CONCLUSIONS AND POLICY OPTIONS

People are pivotal to aviation safety. While humans are largely responsible for commercial aviation's excellent safety record, human errors nonetheless cause or contribute to the vast majority of accidents. Moreover, the rate of pilot error accidents shows no sign of abating, while weather-related crashes are declining and aircraft component failures are rarely the sole factor in serious mishaps. Furthermore, accident and incident data analyses indicate that if only a portion of human error problems can be resolved, substantial reductions in accident risk can be attained.

Changes in aircraft technology and operating practices occurring during the past decade have widespread human behavior and safety implications that are poorly understood. **OTA concludes that human factors concerns regarding cockpit automation, pilot selection and training, and airline management are not addressed adequately by current FARs.**

Human factors is a fundamental technology that is as essential to the safe design and operation of aircraft as are aerodynamics, structures, and propulsion. However, human error hazard analyses are not presently a normal part of aircraft or ATC system design or certification. While the aircraft manufacturing industry and some airlines conduct human factors research, and will continue to do so, this research is fragmented, and the results are not always widely available.

OTA concludes that long-term improvements in aviation safety will come primarily through systematic operational human factors solutions and that such solutions will be found only with consistent, long-term support for research and development. Furthermore, without Federal backing, human factors research and application will languish for proprietary reasons.

FAA could make good use of the multidisciplinary human factors knowledge that is spread throughout the Federal Government, private industry, and independent research groups if it had the organizational structure to coordinate this understanding. For example, in 1985, FAA's Cockpit Human Factors Research Plan drew upon the widespread expertise in the United States and proposed a number of important projects; however, few received sufficient FAA funding. While FAA, as a regulatory agency, might not be expected to conduct much research in-house, FAA must address commercial aviation human factors issues in clear, precise advisory circulars and regulations. **Congress may wish to direct FAA to allocate the resources for human factors expertise in regulatory support staffs, and to establish an agency focal point, such as a Program Office, that could serve as a catalyst and coordinator for cooperative efforts spearheaded by NASA, and including other FAA offices, NTSB, the Department of Defense, manufacturers, airlines, and unions.**

The following are key areas and questions for federally supported research or regulatory efforts:

- *Operational data collection*. Ideally, regulations are based upon objective evidence from the operational environment, one area where the field of human factors is lacking. Federal and industry cooperation is necessary for establishing human performance measurement techniques and for ensuring proper control and dissemination of these sensitive data. Cockpit voice recorders, flight data recorders, and video systems could supply much of these data, provided a nonpunitive approach is taken with close union oversight and support.
- *Physiological and psychological factors*. What are the effects of stressors, singly or in combination, on pilot and controller performance? Advanced technology is changing the roles of pilots and controllers; what cognitive and personality traits are desirable for the operators of current and future aviation systems? What factors influence pilot and controller decisionmaking and what options are available for improving it? How applicable are current age and medical requirements?
- *Crew management*. How can crew coordination be improved? Should CRM training be federally mandated? What technology, procedures, or training methods are available for facilitating intra-cockpit and air/ground communication?
- *New technology*. It is possible to automate most of the flight deck and ATC functions currently performed manually by pilots and controllers; however, not all automation enhances safety. What is the optimal distribution of tasks between operators and automated systems? How can pilot and controller readiness to respond to emergencies be enhanced? What standards are required to ensure effective information transfer to the pilot or controller? How can ATC/cockpit communication be improved? To what extent should flight crewmembers be monitored by automated systems?

Chapter 7

Air Traffic System Technologies

Photo credit: Federal Aviation Administration

An FAA Air Route Traffic Control Center

CONTENTS

Page
Elements of the Air Traffic System 135
  Models for Evaluating Changes to the Air Traffic System 135
  Airports 137
  Airspace 139
The National Airspace System Plan 139
  Air Traffic Control Hardware and Software 140
  TRACON Improvements 143
Training Air Traffic Controllers 146
Collision Avoidance Technology 147
  Ground Collision Avoidance 148
Communications 150
  Navigation 153
  Surveillance 154
Weather Technologies and Training 155
  Windshear 155
  National Weather Service 157
  Air Traffic Control Role 157
  Weather Research and Development 158
Liability Issues 159
Conclusions and Policy Options 159

Figures

Figure *Page*
7-1.Air Traffic Control on a Typical Commercial Flight 141
7-2.Locations of Air Route Traffic Control Centers 142
7-3.Terminal Areas Where Radar Coverage is Provided 144
7-4.Locations of TRACONS With ARTS-IIIA and ARTS-IIIE Equipment....................145
7-5.Locations of Airport Surface Detection Equipment Radars 150
7-6.Windshear Accidents and Incidents Before and After LLWAS Implementation .158

Table

Table *Page*
7-1.Status of Major National Airspace System (NAS) Plan Projects 140

Chapter 7

Air Traffic System Technologies

The Federal Government's major operating responsibility for aviation safety lies in its management of the air traffic system. This system has many individual, interdependent components, each of which affects the safety and capacity of the overall system. Significant components of the current air traffic system are: 1) airports, 2) air route structure, 3) the air traffic control (ATC) system, including hardware, software, and the humans who operate and maintain the system, and 4) communications. Any increase in capacity in one component of the system (e.g., airports) must be accompanied by adequate capacity in the other components for it to have an effect on overall system capacity. In day-to-day operations, the Federal Aviation Administration's (FAA) Central Flow Control uses weather technologies to predict airport capacity, and holds aircraft on the ground when the predicted demand on a destination airport exceeds its capacity in bad weather. Other components of the air traffic system include navigation and surveillance systems, as well as collision avoidance technology currently under development to back up the ATC system.

Recent growth in commercial air traffic has exerted pressures on several parts of the air traffic system. For example, air traffic levels have grown enormously since deregulation without a comparable increase in airport capacity. Moreover, ATC centers must operate using aging equipment and some do not have enough adequately-trained personnel. The hub and spoke system of airline operations has "loaded" hub airports with traffic, causing traffic levels to peak sharply at certain periods during the day and increasing schedule disruption when a flight is canceled or delayed because of weather, equipment malfunction, or any other reason.

If demand for air transportation continues to increase and no actions are taken to address capacity issues, delays will increase and the high level of safety now maintained by the ATC system may deteriorate. Because of the complexity of the system, particularly the human element, it is extremely difficult to determine precisely at what point deterioration would occur.

This chapter examines the potential of technology to mitigate the stresses on the air traffic system and to improve its safety, including technologies or procedures that could increase or better utilize the capacity of the system. It also reviews prospects for technologies to improve communication between pilots and controllers in high-density airspace. Finally, it examines technologies to detect and communicate weather conditions to pilots, training to help pilots use the information effectively, and navigation and surveillance systems for controlling aircraft.

ELEMENTS OF THE AIR TRAFFIC SYSTEM

Models for Evaluating Changes to the Air Traffic System

FAA uses models and other means to evaluate how changes in procedures, facilities, technology, and personnel could affect safety and capacity of the air traffic system. However, the mathematical and computer models described below are rough tools; decisions must still depend on astute judgment of humans familiar with the modeled situation.

Risk Models for Procedural Changes.—FAA normally evaluates the safety impact of procedural changes on the basis of operational judgment, supplemented by models of "worst-case" scenarios and other analytical tools.[1] However, this approach does not always relate procedural changes to any objective measure of accident risk. FAA and the International Civil Aviation Organization have developed mathematical models to estimate an upper bound to the risk of oceanic collisions and accidents due to obstructions near the airport. The United States is considering a change in separation standards for the North Pacific based partially on the results of risk modeling performed at FAA's Technical Center. Also, traffic levels across the Atlantic are monitored, and if the traffic levels exceed a threshold determined by the risk model, FAA may intervene and change separation standards. The collision risk model for obstructions is used by FAA, for example, in cases when obstacles, such as tall buildings, encroach on airspace close to runways.

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[1] For example, see A.L. Haines and W.J. Swedish, The MITRE Corp., "Requirements for Independent and Dependent Parallel Instrument Approaches at Reduced Runway Spacing," Report No. FAA-EM-81-8, prepared for the U.S. Department of Transportation, Federal Aviation Administration, May 1981.

Currently, FAA does not have risk models to use in its evaluations of procedural changes in the terminal area, such as the recent reduction in minimum instrument flight rules (IFR) separation standards for certain aircraft types. FAA's monitoring of operations under the new standards has not revealed operational problems that would cause FAA to revert to the original separation standards. However, because aircraft accidents are exceedingly rare, a huge number of observations over a number of years would be necessary to identify a rise in risk because of this change. A risk model for the terminal area would also suffer from lack of data on low-probability events. For this reason, risk models, no matter how well constructed, are not adequate in themselves for evaluating the safety impact of procedural changes in the terminal area. However, quantitative risk models for the terminal area could, if properly developed and used in conjunction with an assessment of the impact of human error, contribute to the evaluation of procedural changes. FAA is beginning to build a terminal area risk model at the Technical Center. Support for development of the model and for thorough external review of the model by risk experts in other industries, such as the nuclear industry, would help make available a potentially useful, but limited, analytical tool.

System Capacity Enhancements

FAA estimates the potential benefits from new terminal airspace control procedures, terminal ATC automation, and construction of new runways based on a model relating total yearly flight delay hours at any airport to the number of air carrier and other operations, IFR and visual flight rules (VFR) capacity, and the percentage of time that IFR conditions prevail during a year. The model was developed from data available from 32 airports for 1983 and 1984, and from 10 airports for 1985. Enhancements are evaluated by estimating the increase in IFR capacity at each airport where the enhancements could be applied using existing FAA models for airport capacity under instrument meteorological conditions. The overall model is then used to estimate total yearly delays, and finally, delays for all 240 airports are considered.[2] The model is not detailed, and estimates delays without regard to airline scheduling, en route ATC procedures, and routing of traffic flows. The model can therefore be used to suggest the approximate magnitude of future capacity problems and effects of airport enhancements only; it is not suitable for comprehensive capacity examination.

SIMMOD is a model which simulates aircraft movements and controller actions. Runways and an airspace configuration are put into the model, airplanes are fed in, and the model keeps track of the statistics of travel times from point-to-point, delays and fuel burn. SIMMOD was originally designed as a fuel-burn model and was only recently adapted for capacity modeling. SIMMOD is a very detailed model, and system capacity can be estimated only by trying to push as many airplanes as possible through the system by trial-and-error. SIMMOD is a useful tool for evaluating airspace reconfigurations, but it is too detailed for a system-wide statistical evaluation.

System-Wide Performance Models.—FAA is currently involved in a modeling effort, called National Airspace System Performance Analysis Capability (NASPAC), to evaluate the system-wide implications of changes in scheduling, airport capacity, airways, and flow control. According to current plans, the models will evaluate airport capacity characteristics, and model traffic flows between airports, keeping track of how delays propagate to later times. If successful, NASPAC could be especially useful as an analytical support tool for FAA at the FAA/Office of the Secretary of Transportation airline scheduling meetings (see chapter 2). Beyond these scheduling meetings, the models could provide guidance for evaluating operational and technological changes to the National Airspace System (NAS), form the basis for improved real-time capacity management decisions, and support broader policy decisions on demand management as traffic levels increase.

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[2] Transportation Systems Center, "Airport Capacity Enhancement Plan," DOT/FAA/CP-87-3, prepared for the Airport Capacity Program Office, Federal Aviation Administration, 1987.

Airports

Although there has been considerable airport expansion in the United States since 1978, the last major commercial airport built in this country was Dallas/Ft. Worth, completed in 1973. Only two new airports are definitely planned for the future; one about 17 miles from Denver to replace Stapleton Airport, and the other in Austin, Texas. The Denver airport would open with a minimum of six runways and would allow simultaneous IFR approach in both the North/South and East/West directions.[3] Commercial airports take many years to construct, so near-term relief for airport congestion must be found in other ways. Runway capacity at existing airports can be constructed more quickly and approximately 18 new runways are currently planned at existing commercial airports. Runways planned for Nashville and Orlando may be completed as early as 1989.[4]

Both departures and arrivals at airports are severely curtailed by bad weather. FAA has set weather criteria for VFR and airlines plan their schedules for VFR weather conditions, although commercial airlines fly under IFR regardless of meteorological conditions. Flights are held on the ground at departure airports by FAA's Central Flow Control Facility when the number of scheduled flights exceeds an airport's capacity to receive them due to bad weather. Most commercial flight delays over 15 minutes are caused by weather;[5] thus, FAA is particularly interested in procedural changes to increase airport capacity under poor weather conditions.

Currently, simultaneous independent use of converging runways is not permitted except when the cloud ceiling is 500 feet or more and visibility is at least 1 mile, because of concern about simultaneous missed approaches by both aircraft. During bad weather, such use of parallel runways is allowed only when the runways are at least 4,300 feet apart; dependent simultaneous use of parallel runways is permitted only when the runways are at least 2,500 feet apart; and triple parallel runways cannot be used simultaneously. Each of these procedural rules is being examined by FAA as part of its Airport Capacity Enhancement Plan; they could potentially be liberalized to allow more operations under instrument meteorological conditions. Reducing requirements on runway spacing for independent parallel IFR approaches would require a precision approach radar and a controller position to monitor the space between the runways—such a controller position is always required for independent parallel IFR approaches.[6] Not all airports would be affected by these potential changes, because their applicability depends on the runway configuration at the airport.[7]

FAA recently reduced minimum IFR aircraft separation standards for certain aircraft types on final approach from 3 miles to 2.5 miles at airports with taxiways that permit an aircraft to exit a runway within 50 seconds of touchdown and if other conditions are met. The exit time restriction is necessary because no aircraft is permitted to land on a runway already occupied by another aircraft. Twenty-five airports have been approved for the reduced separation standard, and other airports may be eligible in the future if high-speed exits are built for existing runways. However, the reduction is controversial because the 50-second runway time requirement is subject to disagreement, and because the pilot of an aircraft trailing another by 2.5 miles has less time to make altitude or lateral adjustments to avoid the wake vortex of the leading aircraft, a potential problem in bad weather. Moreover, some pilots are uneasy about operating so close behind another aircraft without any means of estimating separation.

Cockpit display of traffic information, applied as a backup to ATC, could mitigate some of these concerns. Nearby traffic has been displayed in the cockpit in tests of the Traffic Alert/Collision Avoidance System (TCAS), although the usefulness of a TCAS display on final approach has not yet been established. FAA plans to test TCAS display use during closely-spaced parallel runway demonstrations in 1988 and 1989. Another option, which may become feasible in the future, is to send surveillance radar data to the cockpit over data link. However, this option raises major operational questions about the roles of pilots and air traffic controllers in maintaining aircraft separation.

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[3] Wayne J. Barlow, director, Northwest Mountain Region, Federal Aviation Administration, letter to OTA, Dec. 22, 1987.

[4] Arnold Price, deputy director, Airport Capacity Program Office, Federal Aviation Administration, letter to OTA, Dec. 17, 1987.

[5] Transportation Systems Center, op. cit., footnote 2.

[6] Arnold Price, deputy director, Airport Capacity Program Office, Federal Aviation Administration, personal communication, Nov. 13, 1987.

[7] Transportation Systems Center, op. cit., footnote 2.

Another area of potential gain is in automation of terminal area ATC for more efficient metering of traffic, particularly during bad weather. FAA is starting a program to develop automated terminal systems for eventual implementation around the year 2000.[8]

FAA has estimated the potential benefits from improved terminal airspace control procedures, terminal ATC automation, and construction of new runways (as planned in 1986) using the airport capacity enhancement model described earlier. Although uncertainties remain, the results suggest that the improvement from enhancements cannot compensate for the additional delays caused by projected increases in air traffic levels through 1994. Even with all the enhancements, the projected delay per flight would be 96 percent of its current value. The model projects 114,500 aircraft hours saved compared to a projected increase of 445,000 aircraft hours without enhancements.[9]

Some capacity gains are also possible from the Microwave Landing System (MLS), depending on airport runway configuration and location with respect to topographical features and other airports. However, locally imposed airport noise restrictions may limit the curved and segmented approaches theoretically possible with MLS. Additional airborne computer equipment must still be developed, and MLS will probably not significantly affect airport capacity in the near future because the current Instrument Landing System (ILS) will be widely available until at least 1998, and consequently not all aircraft will convert to MLS. FAA studies suggest difficulties in controlling aircraft making curved or segmented approaches in a mixed ILS/MLS environment.[10]

Greater use of existing military airports for commercial operations instead of building new airports or additional runways can alleviate some airport capacity problems. As of 1984, there were 24 joint-use airports—military airports with agreements to support some commercial operations.[11] However, using these airports for high-volume commercial traffic could produce local noise problems and restrict flexibility for military flights, while security limitations could interfere with efficiency of commercial operations. Furthermore, military airports generally do not have sufficient facilities for conveniently handling large numbers of passengers. Finally, the total additional capacity these airports could add to the system is limited. Thus, military airports are a good choice to relieve congestion in some areas in the near term, but other measures are needed to solve the national capacity problem.

Smaller, less used civil airports could also be used as hubbing centers. In fact, as delays at major hubs increase, some airlines are locating hubs at smaller airports, despite the fact that smaller cities have fewer origin and destination passengers than larger hubs. Smaller airports can relieve some stress on large, crowded hub airports, but, depending on local conditions, may not necessarily assist with airspace congestion. Similar tradeoffs apply to the use of reliever airports to receive some general aviation (GA) traffic that would otherwise fly into busy hub airports.

Noise and congestion problems attendant to airports near big cities have prompted proposals to build large airports far from cities for use as hubbing centers. Using airports strictly as hubbing centers is a radical concept by current standards, because airlines need substantial revenues from origin and destination passengers. This situation could change, however, if traffic levels continue to grow and hubbing persists. FAA is currently exploring high-speed rail or advanced vertical and short takeoff and landing aircraft for transporting passengers rapidly from city centers to distant airports.[12] Advanced rapid transit could help keep commuting times to remote airports comparable to commuting times to large hub airports today.

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[8] Ibid.

[9] Ibid.

[10] National Aeronautics and Space Administration and Charles Stafford, "Report on the Simulation of Microwave Landing System Procedures in the New York Terminal Area," unpublished report, 1987.

[11] The Secretary of Defense and the Secretary of Transportation, "The Plan for Joint Use of Military Airfields," pursuant to section 504(d)(3) of the Airport and Airway Improvement Act of 1982, Public Law 97-248, Mar. 8, 1984, p. 2.

[12] Albert W. Blackburn, associate administrator for Policy and International Aviation, Federal Aviation Administration, reported at the Fifth International Workshop on the Future of Aviation, sponsored by the Transportation Research Board, Oct. 6, 1987.

Airspace

The FAA's East Coast Plan and the developing west coast and midwestern airspace reconfigurations represent attempts to reduce delays by configuring air route structure more efficiently. While such efforts can reduce delays, they have associated costs, including having to change ATC facilities and retrain controllers. For example, the East Coast Plan had a big impact on the Boston Air Route Traffic Control Center (ARTCC), which had to be upgraded and full performance level controllers retrained to work with the new traffic flow configuration. These activities slowed down the training of developmental controllers needed to fill a gap in trained personnel in the Boston Center.[13] Another side effect of the East Coast Plan is that flights in and out of Philadelphia have been routinely delayed because of airspace reconfiguration. This is especially damaging to the commuter airlines who attract customers with frequent, on-time flights.[14]

Airspace reconfigurations require careful analysis to minimize unintended side effects, and FAA is implementing the East Coast Plan in phases. By themselves, such changes cannot compensate for future increases in air traffic levels, since airport capacity is also a limiting factor. According to an FAA estimate based on SIMMOD, the East Coast Plan saves about 27 flight hours per day in the region covered by the Boston ARTCC,[15] or 9,855 flight-hours per year. FAA projects the increase in air carrier delays between 1984 and 1994 at 445,000 aircraft hours, assuming no capacity enhancements.[16]

Widebody aircraft.—Several aircraft manufacturers have forecast a trend towards higher-capacity aircraft in response to the airport congestion problem.[17] The major Japanese airlines (Japan Air Lines and All-Nippon Airways) have adapted some Boeing 747 aircraft for high-capacity short-range travel by reconfiguring the interiors. In the United States, however, the trend following deregulation has been towards smaller aircraft. This could change, however, as demand for air travel increases and if airline operations shift from hub and spoke to point-to-point. Also, even though some airlines are purchasing new aircraft, others are retaining older aircraft, slowing the process of replacing smaller aircraft by larger, more expensive ones. Given the current incentives for purchasing smaller aircraft and continuing to use existing smaller types, it is difficult to predict how much use of larger aircraft will actually relieve congestion. Nonetheless, widespread use of high-capacity aircraft for medium- to long-range routes could increase system capacity significantly, particularly if combined with high-speed ground transportation to major hubs.

THE NATIONAL AIRSPACE SYSTEM PLAN

The NAS Plan, developed by FAA and first published in 1981, is a comprehensive plan to modernize and improve airways and aviation facilities. The centerpiece of the NAS Plan is the upgrading of the ATC system to accommodate more traffic with greater efficiency and automation. When it was first presented to Congress, costs for the NAS Plan were projected to be $9 billion over 8 years, but total cost estimates which now include Terminal Doppler Weather Radar, as well as life cycle costs not originally in the NAS Plan, have ballooned to $15.8 billion through the year 2000. NAS Plan financing is described in chapter 3.

All the major programs in the NAS Plan are behind the original schedule by substantial amounts (see table 7-1). Two views as to why the NAS Plan has slipped so far behind schedule are now prevalent. The first view is that Congress has been unwilling to appropriate from the Airport and Airway Trust Fund because the unused fund monies can be applied against the Federal deficit, thereby allowing

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[13] Charles Peahl, assistant manager for Training, Boston Air Route Traffic Control Center, Federal Aviation Administration, personal communication, Sept. 9, 1987.

[14] OTA primary research, 1987.

[15] Price, op. cit., footnote 6.

[16] Transportation Systems Center, op. cit., footnote 2.

[17] James Ott, "Industry Foresees Wide-Bodies as Aid to Congested System," *Aviation Week & Space Technology*, Sept. 28, 1987, pp. 36-37.

Table 7-1.—Status of Major National Airspace System (NAS) Plan Projects

Project	Slippage[a]	Reason for slip
Host Computer	6 months	Contractor delays in software coding and documentation
Advanced Automation System	2 years	Additional requirements added and provision for preproduction testing
Voice Switching and Control System	1 year	Additional requirements (number of operational positions, redundancy) and testing to reduce risk
Flight Service Automation System	2 years	Software development problems
Automated Weather Observing System	2 years	Contractor difficulty complying with Critical Design Review requirements and failure to perform required quality assurance procedures
Central Weather Processor	3 years	Addition of prototype phase, redefinition of statement of work with contractor (NASA/JPL), less than optimum contractor staffing
Long-range radar (Air Route Surveillance Radar: ARSR-4)	4 years	Delay in consummating FAA/USAF agreement on number of systems required and funding
Mode S	4 years	Prototype added, clarification of specifications, revised test plan, contractor late meeting critical design review
Airport Surveillance Radar (ASR-9)	3 years	Delay in completion of critical design review, problems in system integration testing, FAA rejection of inadequate test procedures, contractor problem obtaining critical parts
Microwave Landing System	2 years	Delay in contractor software coding
Radar Microwave Link	1 year	Implementation started in 1986
Terminal Doppler Weather Radar	1 year	Revision of draft project specification, evaluation of impact of various siting options

KEY: NASA/JPL = National Aeronautics and Space Administration/Jet Propulsion Laboratory; FAA = Federal Aviation Administration; USAF = U.S. Air Force

[a] Amount of slippage in initial implementation comparison 1983 NAS Plan with draft 1987 Plan.

SOURCE: Office of Technology Assessment based on General Accounting Office, 1987 and Federal Aviation Administration, letter to Office of Technology Assessment, Jan. 15, 1988.

government funds for other purposes to be appropriated under the Balanced Budget and Emergency Deficit Control Act of 1985. The second view is that FAA has not been able to spend money on NAS Plan procurements because of engineering problems, particularly in software development, and changes in technology requirements caused by unanticipated developments in air transportation since 1981. While both views contain elements of truth, the General Accounting Office (GAO) contends that NAS programs have fallen behind because the original plan did not anticipate the time needed to tailor existing technology to ATC system requirements and did not provide time for adequate development and testing.[18] However, delays and cost increases of the magnitude experienced for the NAS Plan are not unusual for large and complex technological programs throughout the Federal Government.

FAA also maintains a plan for research, development, and engineering to investigate areas of technology not covered in the NAS Plan, and to fully exploit NAS Plan technologies.[19]

Air Traffic Control Hardware and Software

ATC facilities at all levels—airport towers, Terminal Radar Approach Control (TRACON) facilities, ARTCCs, and the Central Flow Control Facility (see figure 7-1)—experience the stresses of high traffic levels. The original version of the NAS Plan called for substantial changes in ATC facilities, including automation, to handle increased traffic by the early 1990s,[20] but most of the major changes are not now expected until the late 1990s and be-

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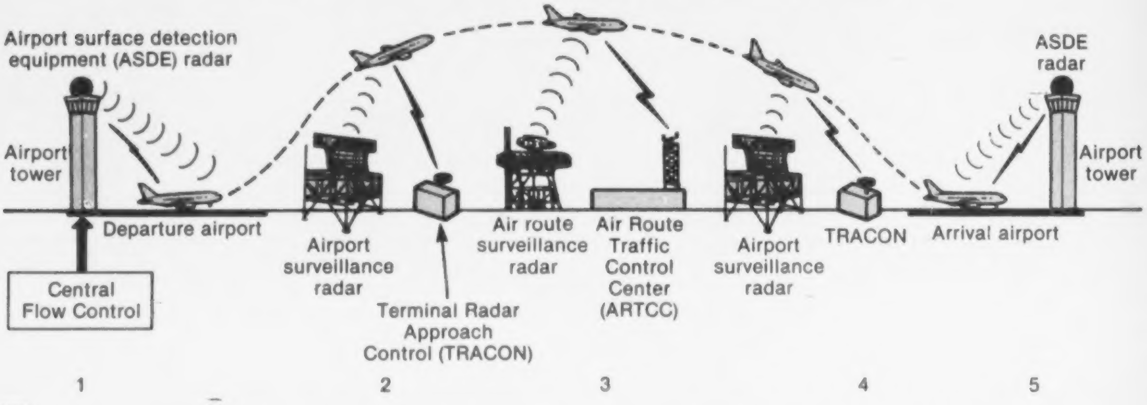
[18] Herbert McLure, associate director, Resources, Community and Economic Development Division, General Accounting Office, "National Airspace System (NAS) Plan Delays," testimony before U.S. Congress, Senate Committee on Commerce, Science and Transportation, Subcommittee on Aviation, Apr. 8, 1987.

[19] U.S. Department of Transportation, Federal Aviation Administration, "The Federal Aviation Administration Plan for Research, Engineering and Development," vol. 1, draft manuscript, August 1987.

[20] U.S. Department of Transportation, Federal Aviation Administration, *National Airspace System Plan* (Washington, DC: December 1981), pp. III-8, III-9, IV-6, and IV-7.

Figure 7-1.—Air Traffic Control on a Typical Commercial Flight


Airport surface detection equipment (ASDE) radar
Airport tower
Departure airport
Central Flow Control
Airport surveillance radar
Terminal Radar Approach Control (TRACON)
Air route surveillance radar
Air Route Traffic Control Center (ARTCC)
Airport surveillance radar
TRACON
Arrival airport
ASDE radar
Airport tower
1
2
3
4
5

KEY:
1. The airport tower controls the aircraft on the ground before takeoff and then to about 5 miles from the tower, when the tower transfers aircraft control to a Terminal Radar Approach Control facility (TRACON). Controllers in the airport tower either watch the aircraft without technical aids or use radars—Airport Surface Detection Equipment for aircraft on the surface and airport surveillance radar for those in the air. Central Flow Control (in Washington, DC) can order the tower to hold flights on the ground if demand exceeds capacity at the arrival airport.
2. The TRACON, which may be located in the same building as the airport tower, controls aircraft from about 5 miles to about 30 miles from the airport, using aircraft position information from the aircraft surveillance radar. The TRACON then transfers control of the aircraft to an Air Route Traffic Control Center (ARTCC).
3. ARTCCs control aircraft that are en route between departure and arrival airports. Each ARTCC controls a specific region of airspace and control is handed off from one ARTCC to another when a boundary is crossed. Aircraft positions are detected by the air route surveillance radar. The last ARTCC on the flight path transfers control to a TRACON when the flight is about 30 miles from the arrival tower.
4. The TRACON controls the arriving aircraft until it is within about 5 miles of the arrival airport tower, when control is transferred to the tower.
5. The airport tower controls the aircraft on the final portion of its approach to the airport and while it is on the ground.

SOURCE: Office of Technology Assessment, 1988.

yond.[21] Automated tools for controllers can reduce workload, provide information to reduce the amount of potentially error-prone mental judgments controllers now must make, permit better teamwork, and enhance the working environment. While automation can facilitate safe handling of higher traffic levels, a high degree of automation changes the role of the air traffic controller and may in itself introduce new hazards.

Installation of the Host computer at ARTCCs (see figure 7-2), the first major step in FAA's plan to modernize ATC, is the most significant technology measure taken in recent years to ease capacity problems. The old system would occasionally overload and fail, increasing the risk that other events or human errors could snowball into an accident. The Host computer has much more capacity and speed then the old system, and includes backup by an identical computer system in case of failure.

FAA plans to further modernize ATC equipment and software in a series of steps. According to current plans, the contractor (either Hughes or IBM) for the modernization will be chosen in July 1988. The next major step in the process will be to replace controller consoles with the Interim Sector Suite System. Then, hardware for the Terminal Advanced Automation System will be installed and software for approach/departure control introduced. Next comes computer hardware and software for en route ATC, called the Area Control Computer Complex. Finally, en route software called Advanced En Route Automation (AERA) will be introduced. The name for the whole system of modernized ATC hardware and software is the Advanced Automation System (AAS). FAA's acquisition strategy for AAS has been criticized by GAO for being too risky; it does not conform with the principles fundamental to Office of Management and Budget Circular A-109 on major systems acquisition.[22] FAA intends to test

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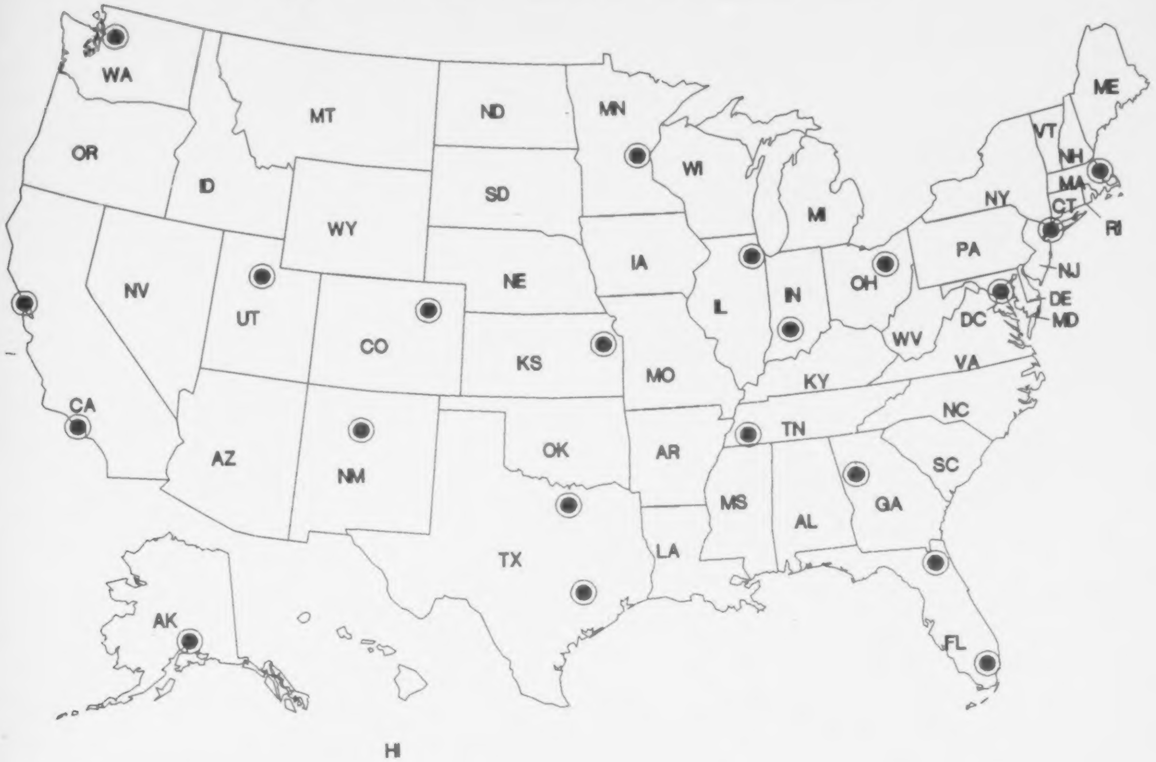
[21] U.S. Department of Transportation, Federal Aviation Administration, *National Airspace System Plan* (Washington, DC: April 1987), pp. III-9, III-9, III-52, and III-53.

[22] U.S. Congress, General Accounting Office, *Air Traffic Control: FAA's Advanced Automation System Acquisition Strategy is Risky*, GAO/IMTEC-86-24 (Washington, DC: July 1986).

Figure 7-2.—Locations of Air Route Traffic Control Centers



SOURCE: Federal Aviation Administration.

the system in partnership with a single prime contractor to take advantage of FAA's ATC and operational experience.

An issue more basic than strict compliance with Circular A-109, however, is whether the process fosters innovative approaches to satisfy real ATC needs in an appropriate time. Emphasis on analytical tools for identifying ATC system needs and on early prototyping and streamlined procurement processes could facilitate timely fielding of new technology [23] and evaluation of alternate approaches to help ensure adequate solutions to ATC problems.

According to current plans, AERA will be implemented in three stages: the first, called AERA-1, will predict the future positions of aircraft using flight plan information and alert controllers when potential conflicts occur between planned flight paths up to approximately 20 minutes into the future. Pilots may also be able to change flight plans en route, and a computer would automatically test the flight plan for potential conflicts with other flights. AERA-2 will provide controllers with several alternate resolutions to potential conflicts and will improve coordination between controllers. AERA-3 is not fully defined, but the basic plan is to have the computer select the proper resolution of conflicts and communicate course and altitude changes directly to aircraft.

FAA's original cost-benefit justification for AAS included benefits from more controller productivity, and fuel and passenger time savings from more efficient routes. However, GAO criticized that original analysis severely. Currently, FAA justification is that traffic levels will increase in the future sufficiently that controllers for en route control sectors will not be able to handle it, and ATC must be automated or more flight delays will occur. Preliminary FAA estimates suggest that flight delays will be substantial after about year 2000. However, the model used to estimate the magnitude of delays assumes the distribution of traffic by time of day is the same as today. This distribution is likely to change significantly because of airport capacity limitations and the changing proportion of nonbusiness travelers. Much more work is needed to identify ATC needs for the future and to evaluate potential approaches to meet the needs.

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[23] The President's Blue Ribbon Commission on Defense Management, *A Quest for Excellence: Final Report to the President* (Washington, DC: U.S. Government Printing Office, June 1986), pp. 55-57.

TRACON Improvements

Current ATC equipment is limited in a number of ways. FAA's original plan was to consolidate ARTCCs and TRACON facilities to form Area Control Facilities, but that concept is being reevaluated. Objections to the consolidation are partly operational and partly due to increased vulnerability of the entire system to military destruction. TRACON facilities, in particular, will be affected by a rule (required by recent legislation) mandating altitude-encoding transponders for all aircraft flying above 6,000 feet and in terminal areas where radar service are required.[24] Locations of these terminal areas are shown in figure 7-3. Relief by AAS is not expected until around the year 2000. The New York TRACON already has overloaded computer equipment, because it is served by more airport surveillance radars than its equipment (called ARTS-IIIA) was designed for. Efforts are under way to upgrade its capabilities in three phases ending in 1990.

However, within a few years, other ARTS-IIIA TRACONs, whose locations are shown in figure 7-4, will also have increased transponder traffic levels, and their performance could suffer if their capacity is not upgraded. Processing capability at ARTS-IIIA TRACONs is modular—in the form of up to eight input/output processors (IOPs), although no TRACON except New York has more than four. Each IOP costs about $200,000, and if each of the approximately 60 ARTS-IIIA TRACONs is upgraded by adding four IOP units, the total cost would be around $50 million plus costs for overhead and installation. Despite the fact that IOP units are 15-year-old technology, production lines could be reopened to permit their re-manufacture to provide near-term capacity increases.

Another improvement for TRACONs would be installation of a Mode C Intruder Alert function, which could warn controllers of potential conflicts between IFR and VFR traffic. The current conflict alert installed in ARTS-IIIA equipment alerts controllers only of IFR/IFR conflicts. However, Mode C Intruder Alert will produce additional false alarms for the controller, possibly limiting its utility. ARTS-IIIA sites would require additional IOP capacity to handle the Mode C Intruder Alert function in crowded terminal areas, although additional hardware would not be required in less crowded areas. Funding to increase TRACON computer capacity is included in FAA's fiscal year 1989 budget request, and Mode C Intruder Alert for ARTS-IIIA TRACONs is expected to be included in the 1988 version of the NAS Plan.[25]

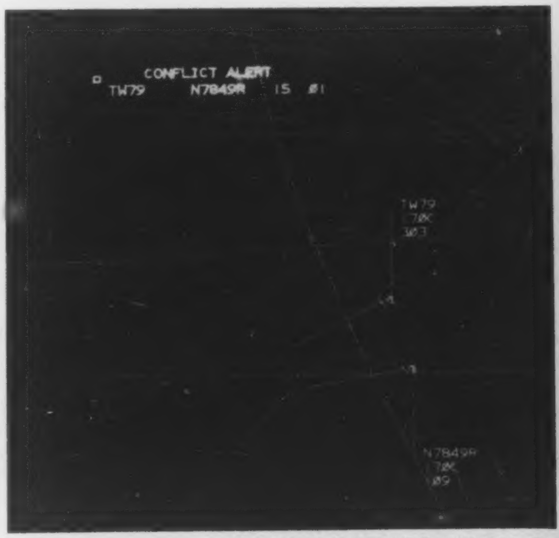

Photo credit: Federal Aviation Administration

An en route air traffic controller's scope shows a conflict alert between two aircraft at the same altitude. The alert tags and the two aircraft data tags blink.

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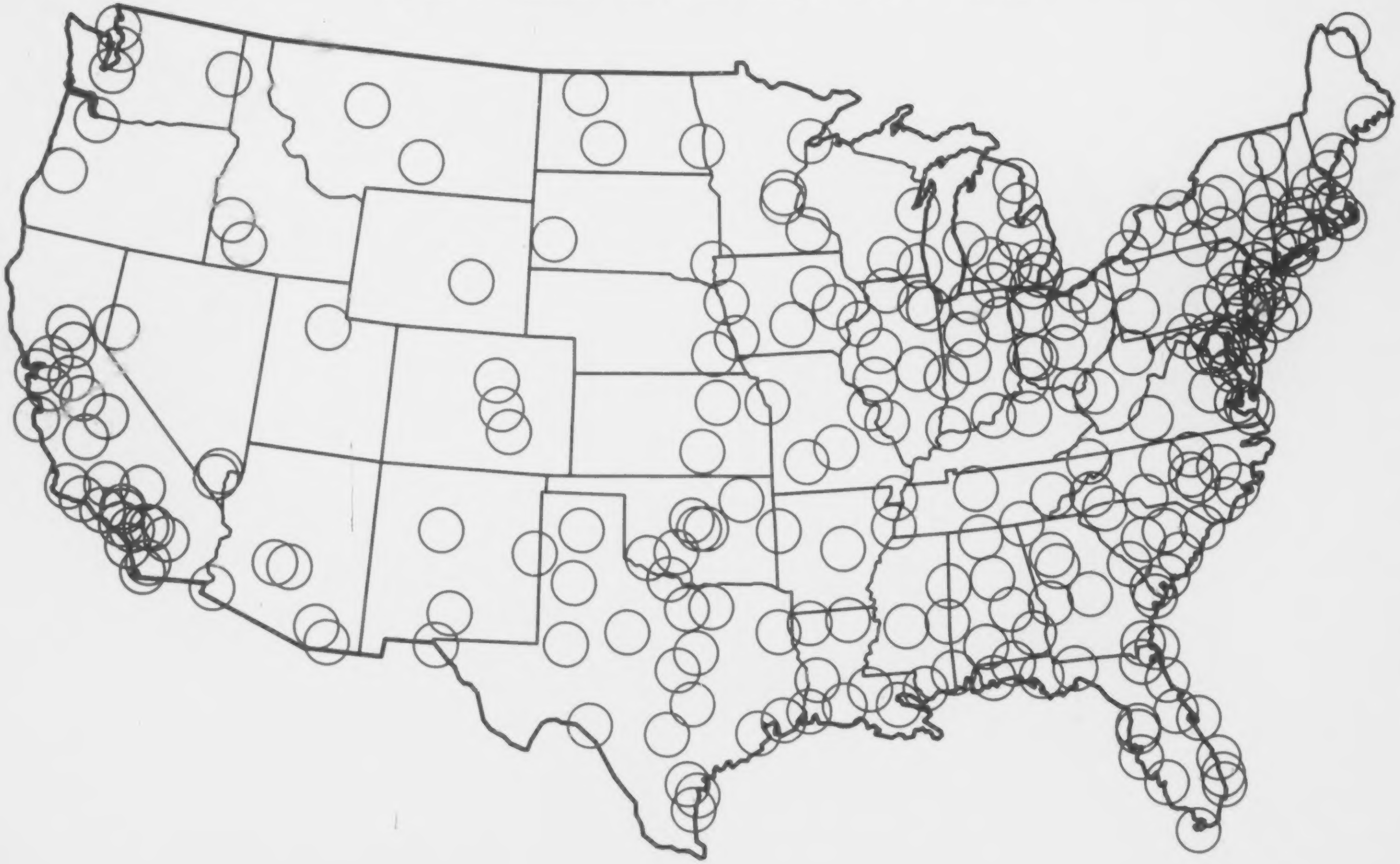
[24] U.S. Department of Transportation, Federal Aviation Administration, "Transponder With Automatic Altitude Reporting Capability Requirement and Controlled Airspace Common Floor," Notice of Proposed Rulemaking, n.d.

[25] Neal A. Blake, deputy associate administrator for Engineering, Federal Aviation Administration, personal communication, Mar. 29, 1988.

Figure 7-3.—Terminal Areas Where Radar Coverage is Provided

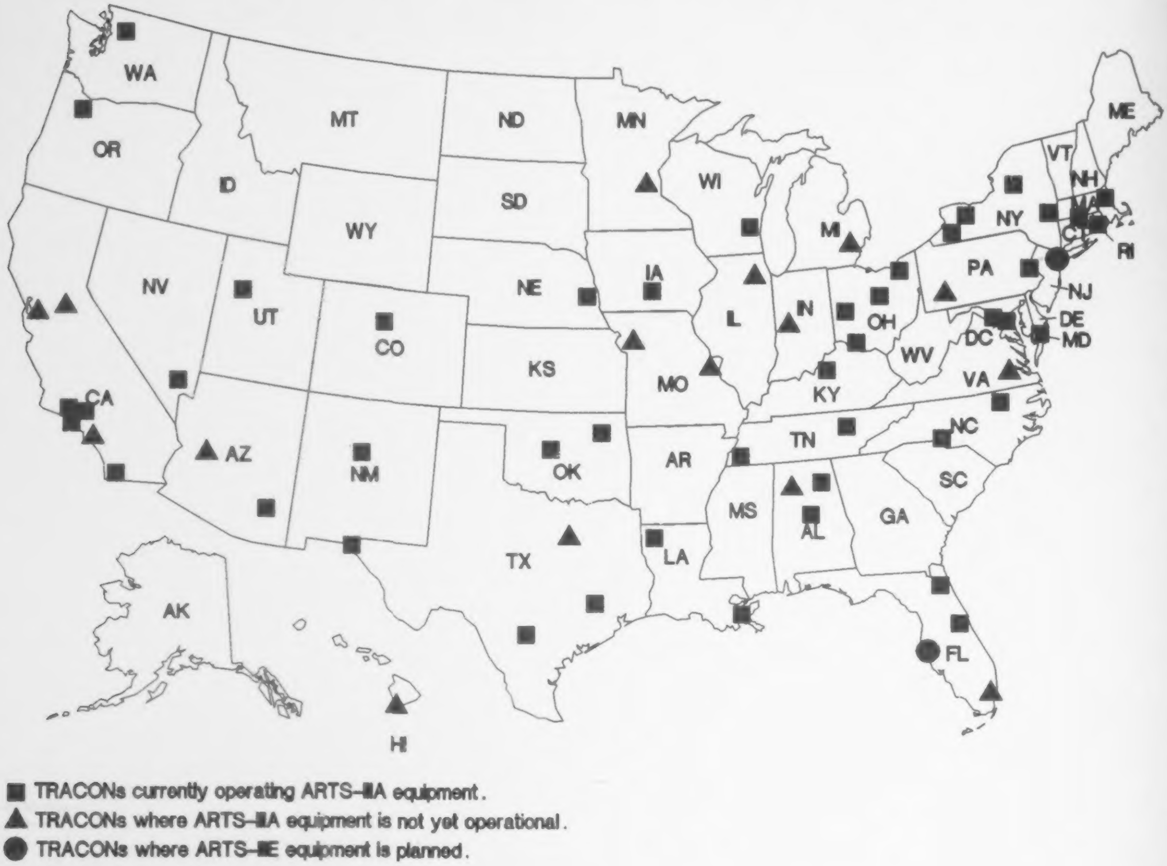


Forty-mile radius circles are shown drawn around each airport.

NOTE: A recent Federal Aviation Administration Notice of Proposed Rulemaking would require Mode C transponders in all aircraft operating within the circled area, regardless of altitude.

SOURCE: Federal Aviation Administration.

Figure 7-4.—Locations of TRACONS With ARTS-IIIA and ARTS-IIIE Equipment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WV
VA
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NM
OK
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TN
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HI
■ TRACONs currently operating ARTS-IIIA equipment.
▲ TRACONs where ARTS-IIIA equipment is not yet operational.
● TRACONs where ARTS-IIIE equipment is planned.

KEY: TRACONS = Terminal Radar Approach Control facility.

SOURCE: Federal Aviation Administration.

Beyond expanding the capacity of TRACONs and installing Mode C Intruder Alert, terminal facilities could be automated to reduce mundane tasks for controllers. Research has been carried out in the United States and Germany on terminal automation and improved controller displays, and FAA's fiscal year 1989 budget request includes increases in funding for terminal automation.[26]

ARTCCs are limited by the number of radar consoles and radars that can be run off the Host computer, limiting expansion possibilities as traffic levels increase. Furthermore, equipment in en route centers is old and is becoming more difficult to replace, and improvements in the basic infrastructure of en route ATC centers are needed. While the general principle of reducing controller workload is sound, other aspects of the cost-benefit analysis for AERA are more questionable. Controllers will be more dependent on automation support if AERA is implemented, and while FAA plans a lengthy period of operational evaluation and functional backup for automated aids, the safety hazards of the changes in the controller's role have not been thoroughly evaluated. Currently, the impact of conflict alerts which extend 20 minutes or more into the future are not well understood either from a system safety or an efficiency standpoint. Further examination of the potential hazards and efficiency gains resulting from automation of controller functions could clarify whether AERA would permit safe control of higher traffic levels.

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[26] Ibid.

TRAINING AIR TRAFFIC CONTROLLERS

Air traffic controller training is an immediate concern because many ARTCCs and airport towers have a shortage of adequately trained personnel. Some en route facilities report that the current number of personnel is adequate to staff the center, but that many of their controllers need further training to enable them to operate more positions. Training to full performance level at an ARTCC generally requires over 3 years, although sufficient training to operate two positions (at which point the controller is called an operational controller) takes less time.[27] Even if present training needs are met, it is likely that a large number of new controllers will need to be trained in the near future, because many current controllers are approaching retirement age.

Prospective air traffic controllers, called "developmentals," are screened and receive the initial portion of their training at the FAA Academy in Oklahoma City, Oklahoma; then they are sent to an ARTCC or tower for the next stages of training. Only about 60 percent of the developmentals who attend the initial training session at Oklahoma City pass the screening process, which requires them to separate aircraft without radar. A 3-week course at Oklahoma City follows the initial training session for developmentals being trained for towers. This course includes training in a scale mock-up of a tower, with small models of aircraft moved around by hand outside the mock-up to simulate airport traffic. Developmentals training for ARTCCs undergo radar training with simulations created through the hardware and software of a system called Dynamic Simulation (DYSIM). DYSIM ties into the operational computer of the ARTCC, presenting the trainee with simulated traffic of limited realism. TRACONs and airport towers with radar have a radar simulator training system similar to DYSIM called Enhanced Target Generator.[28] Beyond simulator and classroom training, ARTCCs, TRACONs, and towers rely heavily on on-the-job training for developmentals.

The Seattle ARTCC uses an upgrade of DYSIM, called Computer Enhanced Radar Training (CERT), which has improved software that more realistically simulates sector traffic. The CERT program emphasizes good use of instructors and the proficiency of operators who simulate pilots. As a result of these improvements, the Seattle ARTCC has cut by over 50 percent the time needed at certain stages of controller training, and has reduced time spent for on-the-job training with live traffic by 18 percent.[29]

The realism of training is limited, because software does not allow simulated traffic to deviate from preferential arrival and departure routes in the live

Photo credit: Federal Aviation Administration

Air traffic controller trainees receive instruction at the Seattle Air Route Traffic Control Center's Computer Enhanced Radar Training (CERT) laboratory.

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[27] Peahl, op. cit., footnote 13; Ron Wiest, assistant manager for Training, Chicago ARTCC, Federal Aviation Administration, personal communication, Sept. 10, 1987; Richard Dilley, assistant manager for Training, Los Angeles ARTCC, Federal Aviation Administration, personal communication, Sept. 11, 1987.

[28] Ann Spence, air traffic subject matter expert, Federal Aviation Administration, personal communication, Aug. 27, 1987.

[29] U.S. Department of Transportation, Federal Aviation Administration, "Seattle Center Computer Enhanced Radar Training Staff Study," unpublished manuscript, n.d.

system,[30] and the call signs of simulated traffic must begin with XXX, a pattern never encountered with real traffic. Moreover, some ARTCCs lack sufficient equipment to train all their developmentals simultaneously, so developmentals spend more time at intermediate levels than may actually be necessary.[31] In other ARTCCs, on-the-job training of developmentals is an additional and taxing task for full performance level controllers.[32] To deal with these problems, a few ARTCCs have begun sending controllers back to Oklahoma City for site-specific radar training at the Academy.[33] At Oklahoma City, developmentals receive increased personal attention and specific remediation, perhaps more important than the Academy's more versatile radar simulation capabilities.[34]

These alternatives point to possibilities for near-term improvements to training capabilities at ARTCCs. For the longer term, airline pilot training could be used as a model, with microcomputers for basic subsystem training and realistic simulators for full operations. Combined with appropriate levels of individual attention, simulator training could reduce or even eliminate the need for on-the-job training of developmentals and reduce the time needed to reach operational and full performance levels. FAA is now taking a first step by revising its Instructional Program Guide for en route training to increase site-specific simulator training at each ARTCC.[35]

COLLISION AVOIDANCE TECHNOLOGY

Traffic Alert/Collision Avoidance Systems (TCAS) provide independent backup to the ATC system and help pilots fulfill their responsibility to see and avoid other aircraft. Three types of TCAS capability are being developed: TCAS-I, TCAS-II, and TCAS-III. TCAS-I, the least sophisticated of the systems, warns of nearby traffic by giving traffic advisories that indicate the approximate bearing of each threat and the approximate altitude, if the threat aircraft is equipped with an altitude-encoding transponder. TCAS-I is intended for GA use and for small commercial aircraft. TCAS-II and III also supply resolution advisories to help the pilot maneuver away from an impending collision or close approach. TCAS-II can advise only vertical maneuvers, while TCAS-III can advise both horizontal and vertical maneuvers. TCAS-II and III are intended for use on large jet aircraft and turbine-powered commuter aircraft.

All three systems require the threat aircraft to have an operating transponder to function in the traffic advisory mode; resolution advisories are generated by TCAS-II and III only if the threat aircraft has an operating altitude-encoding transponder. The Mode S data link communications system, now being developed by FAA, will be used for air-to-air interrogation/reply with TCAS-II and III to coordinate maneuvers when two TCAS-equipped aircraft must evade each other.[36]

TCAS-II, the most advanced in development of the three systems, is currently undergoing flight testing scheduled for completion by the end of 1988. TCAS-III has had initial flight tests, but technical challenges remain in collision avoidance logic, human factors, interaction with ATC, certification standards, verification tests, and performance monitoring. TCAS-I development is not as far along as either II or III.[37]

Current TCAS issues include the adequacy of vertical-only maneuvers for collision avoidance, as supplied by TCAS-II. TCAS-III would provide horizontal and vertical maneuvers, but will not be available soon; moreover, it is projected to cost about $20,000 to $30,000 more per copy than TCAS-II.[38] FAA

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[30] A.T. Snelson, air traffic manager, Seattle ARTCC, Federal Aviation Administration, personal communication, Aug. 18, 1987.

[31] Peahl, op. cit., footnote 13.

[32] Dilley, op. cit., footnote 27.

[33] Dennis Burke, manager, Chicago ARTCC, Federal Aviation Administration, personal communication, Sept. 10, 1987.

[34] B. Keith Potts, Federal Aviation Administration, attachment to letter to OTA, Feb. 22, 1988.

[35] Ibid.

[36] 52 *Federal Register* 32269 (Aug. 26, 1987).

[37] Joseph Fee, TCAS program manager, Federal Aviation Administration and Dan Tillotson, senior project leader, ARINC Research, Inc., presentation at Air Line Pilots Association 1987 Safety Forum, Aug. 19, 1987.

[38] Ibid.

Photo credit: Federal Aviation Administration

FAA pilots flight-test a collision avoidance system.

has issued a Notice of Proposed Rulemaking requiring TCAS-II in all Part 121 aircraft and larger Part 135 aircraft with turbine engines, and encouraging manufacturers to build TCAS-II units that can be upgraded to TCAS-III without major changes in hardware. The Airport and Airways Safety and Capacity Expansion Act of 1988 requires development of TCAS-II with standards upgradable to TCAS-III.[39]

GA aircraft operating without transponders will remain problems; since TCAS warns only of aircraft with operating transponders and provides a resolution advisory only if the threat aircraft has an altitude-encoding transponder. FAA rulemaking to require Mode C (i.e., altitude-encoding) transponders on aircraft flying above 6,000 feet and in terminal airspace where radar coverage is provided will induce GA pilots to buy altitude-encoding transponders. Currently, Mode C transponders are required only above 12,500 feet and in Terminal Control Areas. This FAA rulemaking was mandated by Congress as part of a program to reduce the potential for midair collisions. Even with the increased Mode C requirements, a small plane operating without a Mode C transponder could still inadvertently enter terminal airspace with radar coverage. A program to gradually require transponders in all aircraft would provide additional safeguards.

Technical uncertainties still surround TCAS, because the reactions of controllers and air traffic patterns to TCAS-induced altitude changes are relatively untested. The major potential ATC problem is a threat to a third aircraft if an aircraft suddenly changes direction or altitude. Simulations suggest such a problem is extremely unlikely. Because of the complexity of retrofitting TCAS to existing aircraft, it will be gradually introduced, easing potential ATC adjustments.

Ground Collision Avoidance

Although the United States has had few fatalities from collisions on the surface at airports, a number of nonfatal collisions and close calls have occurred. As traffic levels increase the probability of a disastrous ground collision will increase unless compensatory steps are taken. Twelve major airports have Airport Surface Detection Equipment (ASDE-2) radar to present surface traffic information to controllers (see figure 7-5). This equipment is about 25 years old, expensive to maintain, and has performance limitations. Anchorage, Alaska, has a more advanced surface detection radar. FAA plans to replace ASDE-2 with the more advanced ASDE-3 and to field ASDE-3 at some additional airports. ASDE-3 radar can be enhanced by automatic conflict alert and further automated through digital air/ground communications links.

Other fairly simple means to improve ground collision safety include improved signs on the airport surface, control lights at entrances to active runways, and training pilots and controllers to exercise greater vigilance during taxi operations. First, a short-term research and development (R&D) effort to improve sign symbology could provide input for developing consistent standards for taxiway and runway signs at all U.S. airports. Second, radio-controlled light-

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[39] Public Law 100-223, Sec. 203(b), Dec. 30, 1987.

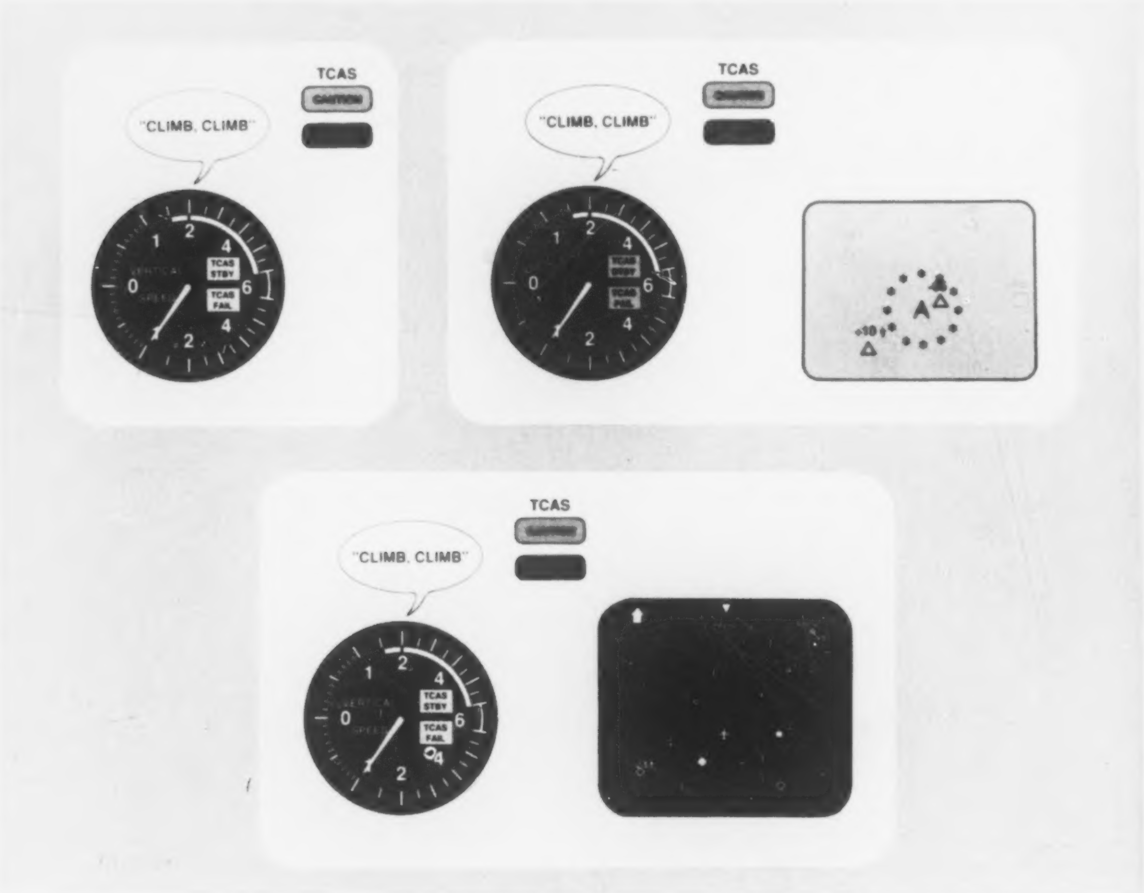


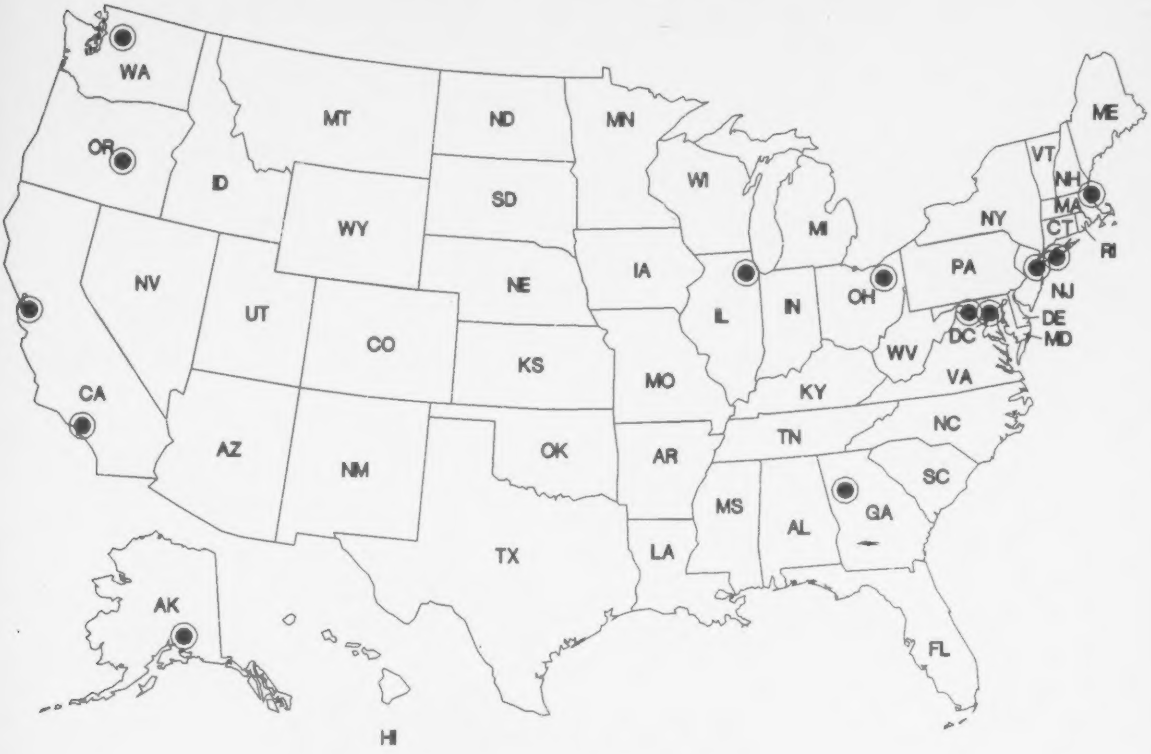
Photo credit: National Aeronautics and Space Administration

Traffic Alert/Collision Avoidance System (TCAS) will provide both visual and aural alerts to the pilot.

ing systems could be installed at entrances to major runways to augment runway clearances from ground controllers. More air traffic controllers for tower operations would be needed to operate the lights. A system of in-pavement stop-bar lights and above-ground signal lights will be tested on 14 runway entrances at JFK Airport (approximately one-quarter of the airport entrances) during 1988. The cost of equipment and installation for the lighting will be about $600,000, but a similar installation at most other major airports would be much more expensive, because, unlike most airports, JFK already has a static bar light system at entrances to runways. Third, training for pilots and controllers on preventing runway incursions could be increased.

For the longer term, work now underway at the FAA Technical Center on sign readability under very low visibility conditions deserves continued support. Also, more advanced sensors for detecting traffic on the airport surface could be developed, along with improved displays for controllers and development of procedures that permit monitoring of the displays as part of a reasonable workload.

Figure 7-5.—Locations of Airport Surface Detection Equipment Radars



NOTE: The ASDE in Anchorage, Alaska is more sophisticated than the systems at the other locations.
SOURCE: Federal Aviation Administration.

COMMUNICATIONS

Ground-to-air communications systems are used to transmit ATC, weather, maintenance, and airline administrative information. Existing communications systems include many types: voice and data systems, one-way and two-way systems, and both government and private-owned systems. Analyses have shown that communication problems are significant sources of system safety vulnerability. For example, FAA reports that controller communication with pilots and other controllers was the second most frequent cause of operational errors at ARTCCs and third at TRACONs.[40] The process of communication between ATC and the aircraft crew is also a significant problem according to the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System database.[41]

The very-high frequency (VHF) voice system linking pilots to FAA ground facilities is a government system primarily used to transmit ATC and weather information, and for flight plan processing. The voice link between pilots and ATC facilities is also the final backup in case all computers or radars fail.

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[40] U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Safety, *Profile of Operational Errors in the National Airspace System, Calendar Year 1986* (Washington, DC: November 1987), p. 4-55.

[41] David C. Nagel, chief, Aerospace Human Factors Research Division, National Aeronautics and Space Administration, letter to OTA, Jan. 26, 1988.

An air traffic controller can operate with multiple frequencies, and may have as many as 30 pilots on one frequency. When many pilots are on the same frequency, each must wait for a gap in communications with the other pilots before transmitting a message, slowing communications in busy airspace. While air traffic controllers are required to issue windshear advisories, they provide weather forecast information only as their higher priority functions of separating aircraft and issuing safety alerts allow. Nineteen percent of controllers responding to a 1985 GAO survey reported they often declined to provide weather information to pilots when working peak traffic periods. Another 34 percent said they occasionally decline to give weather advisories.[42] Air/ground communications is the weakest link in transmission of weather information from sensors, observers, or meteorologists to pilots in flight.

One advantage of having many pilots on the same frequency is that all the pilots on the frequency can hear the messages transmitted and received by other pilots. For example, pilots may transmit pilot reports about weather or runway conditions over the VHF voice link. Other messages that are important to pilots on the "party line" include altitude assignments, ATC clearances, and communication frequency changes.

Radio-frequency failures are less common now than in the past for the ground-based VHF voice link, because most of the aging equipment in the field has been replaced by modern, solid-state equipment, including standby equipment in case the primary equipment fails. Nowadays, when a failure occurs, it is more likely to be caused by problems with the leased telephone lines that connect ATC facilities to transmitters and receivers in the field. The national reliability for en route ground-to-air communications, including both FAA equipment and interconnecting links for fiscal year 1987 was 99.6 percent, up from 99.1 in fiscal year 1978.[43] Because a frequency can be blocked if a microphone is stuck in the transmit position, the Radio Technical Commission of America is currently developing standards for devices to alert pilots when this problem occurs. When completed, the standards could be used as a basis for an FAA regulation requiring stuck-microphone alerters in aircraft. Short-term R&D to determine and validate improved ways to utilize analog voice links could enhance current methods.

The government also operates broadcast voice links for transmission of weather and other information to pilots. Services include the Hazardous In-Flight Weather Advisory Service, which is broadcast from selected navigation stations, and the Automated Terminal Information Service (ATIS). ATIS, which is broadcast from navigation stations located on or near airports, is a continuous broadcast of recorded non-ATC information. ATIS relieves airport tower controllers from having to provide certain environmental and runway use information to individual pilots.

VHF radio has limited range, so it cannot be used for transoceanic flight. Instead, high-frequency (HF) radio is used. However, HF communication is not very reliable and long delays sometimes occur before messages can be received. Over land, the secondary surveillance radar system, described later in more detail, communicates altitude data and a code number assigned by ATC for each aircraft from air to ground.

Aeronautical Radio, Inc. (ARINC), a cooperative owned by over 50 airlines and aviation-related companies, owns and manages the ARINC Communications Addressing and Reporting System (ACARS), a terrestrial digital data link for use by airlines. Nearly 75 percent of the commercial fleet is equipped with ACARS, which provides continuous coverage above 20,000 feet in the United States and on-ground coverage at 95 principal airports.[44] ACARS is used primarily for aircraft operational control and administrative communications, as well as for automatic aircraft reporting, such as allowing an aircraft with a system/servicing problem to alert maintenance to have appropriate resources waiting at the airport for its arrival. Weather information prepared by airlines is also transmitted over ACARS, most of it in textual format,[45] although Northwest Airlines transmits graphical weather information to pilots of its Boeing 757 aircraft over ACARS.[46]

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[42] U.S. Congress, General Accounting Office, *Aviation Weather: Status of FAA's New Hazardous Weather Detection and Dissemination System*, GAO/RCED-87-208 (Washington, DC: September 1987).

[43] Wayne J. Barlow, director, Northwest Mountain Region, Federal Aviation Administration, letter to OTA, Dec. 22, 1987.

[44] R.A. Pickens, vice president, Engineering, Aeronautical Radio, Inc., letter to OTA, July 30, 1987.

[45] Rick Hambly, chief of ACARS section, Aeronautical Radio, Inc., personal communication, Aug. 24, 1987.

ACARS is nearing capacity in the northeastern part of the United States, so ARINC has been developing an upgrade. Enhanced ACARS (EACARS) will use up to six separate frequency channels, instead of the single channel of the current system, and will be capable of transmitting at a higher bit rate than ACARS. In addition, the data will be encoded in a format more compatible with transmission of graphical information.[47]

Other privately-owned communication systems used by commercial aviation include the company radio systems of airlines. Northwest Airlines has an eight-frequency analog radio system, over which it transmits graphical weather information to pilots, using audio tones.[48]

Two fundamentally new types of communications systems are currently being developed for aviation use: the government's Mode S data link and industry's satellite communications systems. The expected proliferation of digital communications links raises the possibility of coordinated development to provide air/ground communication that is more reliable and has better coverage and capacity than any of the individual links.

The Mode S data link, part of the NAS Plan, is a subsystem of the Mode S secondary surveillance radar system. Mode S interrogations can be addressed to individual aircraft, and the signal format allows bursts of data to be transmitted from the ground on interrogations and from aircraft on replies. Thus, if an aircraft is equipped with a Mode S data link transponder, two-way air/ground communication is possible.

Future plans include integrating Mode S data link with the Advanced Automation System to provide digital communications between controllers and pilots, as well as weather information through other interfaces. For the near term, however, a relatively limited set of functions is planned, including fairly simple weather messages, pilot advisories, and confirmation of assigned altitudes and communication frequencies.[49]

Mode S implementation is expected to proceed in two phases, with installation of Mode S secondary radars on the ground sufficient to provide nominal coverage down to 12,500 feet above mean sea level in the United States and down to the surface of major airports by 1992 as the first phase. Phase two will involve installation of more Mode S secondary radars on the ground to provide coverage down to 6,000 feet in the United States by 1994.

Mode S data link is robust because of its decentralization and because adjacent ground radars often have overlapping coverage. However, it is basically a line-of-sight system, likely to have coverage gaps near the surface of airports and in mountainous regions, although some additional coverage could be provided by installing extra omnidirectional antennas at airports. Moreover, Mode S will not provide oceanic coverage and is inefficient for broadcast communications, because messages can be received only by aircraft within the main antenna beam of the interrogator (with, perhaps, some exceptions). In addition, information currently available to pilots over the VHF voice party line will be lost with Mode S data link and other discreetly addressed communications systems, unless special provisions are made to transmit that information.

INMARSAT, an international consortium that operates a global satellite system for mobile communications, is working with three groups, including ARINC, to develop aviation satellite services, mainly for oceanic travel.[50] If disputes over frequency allocation can be resolved, the services could be used by U.S. airlines for oceanic ATC, aircraft operational control, and administrative communications, as well as for passenger phone calls in flight, an economically attractive use. Satellite communications systems are relatively expensive to use. Moreover, if all types of aeronautical communications are in the same frequency band, a system must include a feature to override passenger or administrative communications should a safety-critical message need to be sent. However, a satellite system would provide reliable coverage to the ground over a wide area on the Earth's surface, including oceans, and would be less subject to coverage gaps due to obstructions and multipath effects than terrestrial systems.

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[46] John Dietrich, Meteorology Department, Northwest Airlines, personal communication, Aug. 24, 1987.

[47] Hambly, op. cit., footnote 45.

[48] Dietrich, op. cit., footnote 46.

[49] Joseph Fee, Federal Aviation Administration, personal communication, Sept. 15, 1987.

[50] Jim Clark, Aeronautical Department, Service Development Office, INMARSAT, personal communication, Jan. 6, 1988.

The complementary strengths and limitations of Mode S data link, satellite communications systems, and ACARS, point to the value of an integrated approach to aviation communications. Presently, FAA is developing compatibility standards for ground-to-air digital communications systems, using the Open System Interconnection (OSI) model developed by the International Standards Organization. The OSI model, which has been applied in the past to ground-to-ground communications systems, defines communications systems in terms of universal levels which may be common to more than one system. Ideally, if digital communications systems are standardized and integrated, aircraft will not need dedicated hardware for each system. More importantly from a safety standpoint, a pilot could send a message without specifying a particular communications system, and the integrated system would choose the system based on coverage, capacity, and other considerations. Thus, the integrated system would have more coverage and greater reliability than any individual communications system. Although FAA is developing Mode S standards based on the OSI model, and EACARS and the ARINC satellite system are similarly based,[51] FAA and industry have not yet decided to actually attempt to integrate the communications systems. The integrated system concept for air/ground communications systems has attracted the interest of both government and industry representatives on International Civil Aviation Organization committees.[52]

Although digital communications links hold great promise for the future, they will not replace the current air/ground analog voice communications links as the primary system for real-time ATC and weather information until at least well into the 1990s. A great deal of work is still needed to establish and validate a workable set of services for the digital links, and to implement an integrated system into commercial aircraft cockpits and into ground systems. Issues of what information to transfer over data links, when to transfer it, and to whom, have not been resolved.

Navigation

Navigation systems help the pilot determine position with respect to points on the ground. Instruments on board aircraft use signals from navigation aids or from inertial navigation/reference systems on board to show aircraft position on a display such as a horizontal situation indicator. Inertial navigation systems may include special-purpose computers that provide precise Earth latitude and longitude, ground speed, course, and heading. Integration of navigation systems with automatic pilot allows automatically controlled flight and landings under low visibility conditions. Using the most advanced integrated navigation/automatic pilot systems now available, a pilot could, in principle, fly an airplane automatically from takeoff to landing, except for control of the landing gear, flaps, and engine reversers.

The NAS Plan includes implementation of MLS to replace the current ILS. MLS has several technical advantages over ILS, because it is not susceptible to unintentional signal reflections from structures or terrain on or near the airport, and it operates at a frequency band that can accommodate more locations than ILS. MLS can provide signal-in-space accuracy exceeding the requirements of Category III ILS (the most stringent requirements). However, initial MLS units will operate only at Category I, whereas some ILS sites now operate to Category III. MLS can be implemented on runways near water or in mountainous terrain where ILS cannot be used effectively, and is operationally compatible with heliports and future tilt-rotor landing areas, which ILS is not. Finally, MLS allows curved and segmented approaches to runways, although curved and segmented approaches at many airports will be restricted by operational and noise constraints. MLS may increase the capacity of some airports and reduce the communications load on air traffic controllers. However, control of a mixed population of MLS and ILS traffic will be difficult, so most aircraft flying into an airport would need to be equipped with MLS avionics to realize the maximum capacity gain.[53]

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[51] Rick Hambly, chief of ACARS section, Aeronautical Radio, Inc., personal communication, Sept. 18, 1987; Walter J. Gribbin, Aeronautical Radio, Inc., "AvSat, An Aeronautical Satellite Communications System," unpublished manuscript, n.d.

[52] Earnest Lucier, Federal Aviation Administration, personal communication, Sept. 16, 1987.

The Loran-C navigation system, which gives bearing relative to radio beacon transmitters, has become more popular as a low-cost navigation system with many pilots, and its coverage is being expanded to include the midwestern United States. However, Loran-C does not offer redundant coverage in all areas; the loss of a single transmitter means that many aircraft over a wide area lose Loran-C navigation capability. By 1991, however, a satellite-based navigation system, the Global Positioning System, deployed by the Department of Defense, should be operational, and could be used in conjunction with Loran-C to provide redundant coverage. Such redundant coverage could encourage development of new surveillance concepts based on automatic position reports from aircraft in areas not covered adequately by surveillance radars.[54] Automatic position reports would allow much more accurate surveillance of en route oceanic traffic, enhancing air traffic system capacity over oceans.

Surveillance

Two types of surveillance radars detect the positions of aircraft for presentation to air traffic controllers. Primary radar sends out a beam of radiofrequency pulses and measures the distance to aircraft targets by the time it takes to receive the return pulses reflected from the metal surfaces of the aircraft. Secondary radar sends out pulse-coded interrogations on a radio-frequency beam, which are received by transponders on board aircraft. The transponders reply to each interrogation with a coded response. The replies can be encoded with altitude or identification information. This system of ground interrogators and airborne transponders is known as the Air Traffic Control Radar Beacon System (ATCRBS).

Both primary and secondary surveillance radar systems will be upgraded under the NAS Plan. Aging radars at 96 major airports will be replaced by the ASR-9 radar, which offers improved target and weather detection capabilities that do not exist in the current airport radars. The more modern airport surveillance radars (ASR-7s and ASR-8s) already at airports will be transferred from airports receiving ASR-9s to smaller airports. Many en route surveillance radars along the boundaries of the United States will be replaced by the ARSR-4, which is being developed by FAA and the Air Force. The current ATCRBS secondary surveillance radar system will be replaced by Mode S, which also functions as a communications system. Overall, these upgrades in surveillance capabilities will improve the accuracy of surveillance and increase the reliability of the system, as well as provide better weather and ATC information to pilots.

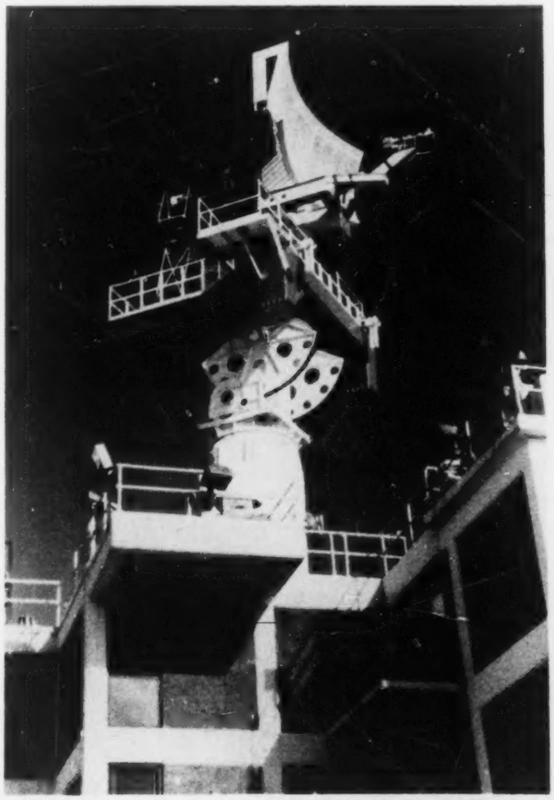

Photo credit: Westinghouse Electric Co.

The first production system of the ASR-9 Airport Surveillance Radar undergoing test at Baltimore-Washington Airport

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[53] National Aeronautics and Space Administration and Stafford, op. cit., footnote 10; Joseph M. DelBalzo, director, Eastern Region, Federal Aviation Administration, "MLS Today for More Capacity and Less Noise Tomorrow," presentation at Royal Aeronautical Society, London, February 1988.

[54] Federal Aviation Administration, op. cit., footnote 20, pp. 6-16 through 6-18.

WEATHER TECHNOLOGIES AND TRAINING

The types of weather of most concern to commercial aviation pilots are: current and forecast surface conditions, convective weather and associated precipitation and turbulence, clear air turbulence, icing, winds aloft (although this is rarely a safety factor), and windshear near the surface. Windshear near the surface is particularly significant because, over the past 10 years, windshear contributed to almost one-half of all fatalities resulting from commercial aircraft accidents during takeoff and landing.

Weather technologies include weather sensors, technologies for data interpretation, message formulation and display, and communications technologies. Other technologies deal with the effects of weather, such as de-icing technologies (which are discussed in chapter 8). Some weather technologies are entirely contained within the aircraft, and others are ground-based, with perhaps a ground-to-air communication link to relay the information to the pilot. Many technologies that address weather also have other functions.

Several generic types of weather sensors are commercially available for use on the aircraft, including weather radar, sferics (atmospherics) detectors, and windshear warning systems. Weather radar presents to the pilot radio-frequency reflectivity levels, which suggest precipitation rate, on a map display. Since turbulence is typically a greater hazard to aircraft than precipitation, methods have evolved for using reflectivity data to infer the probable existence of turbulence. Some newer models of airborne weather radar include a Doppler channel for direct detection of turbulence. From the standpoints of engineering approach and use in the cockpit, Doppler radar remains a developing technology.

Neither conventional nor Doppler airborne radar is capable of reliably detecting clear air turbulence, which may appear separate from storms or in the vicinity of storms. Also, airborne weather radars may be attenuated by nearby precipitation or by ice on the radome, although some newer models have a feature that warns pilots when signals are being attenuated. For these and other reasons, proper use of airborne weather radar is by no means straightforward and requires training and experience on the part of the pilot.

Sferics detectors passively detect electrostatic discharges in the atmosphere. The presence of discharges suggests convective activity where turbulence may be present. Sferics detectors derive the range of detected weather statistically from the strength of received signals. As such, the range of detected weather may be significantly in error. The output displays of both weather radar and sferics detectors may be integrated with the horizontal situation indicator in cockpits equipped with CRT displays, so that the pilot sees weather in relation to navigational aids, waypoints, and intended route of flight on a display.

Federal regulations require weather radar for Part 121 operators[55] and for Part 135 operators when operating large, transport category aircraft.[56] Smaller aircraft with at least 10 passenger seats must carry approved thunderstorm detection equipment;[57] these aircraft may carry an approved sferics detector instead of weather radar.

Windshear

Windshear warning systems use the performance of the aircraft itself as a sensor of conditions that indicate the presence of a potentially dangerous windshear. Of all the possible types of windshear, the microburst is usually the most dangerous, and windshear warning systems are optimized to detect the microburst. Visual and audible alarms sound when performance of the aircraft suggests the presence of a windshear. Newer models of windshear warning systems can provide guidance to assist the pilot to escape the windshear, and the warning system can be coupled to the aircraft's autopilot to automatically execute procedures to escape the shear. The weakness of current windshear warning systems is that the aircraft must already have entered the windshear to detect it; this may be too late to escape the most severe shears. Detecting windshear conditions prior to entry represents a significant technological and economic challenge to the aviation industry.

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[55] 14 CFR 121.357 (Jan. 1, 1987).
[56] 14 CFR 135.175 (Jan. 1, 1987).
[57] 14 CFR 135.173 (Jan. 1, 1987).

Photo credit: The Sperry Corp.

Windshear near the ground is sometimes accompanied by visual signs.

Windshear warning systems are not currently required in aircraft; however, a recent Notice of Proposed Rulemaking would require windshear warning with flight guidance for Part 121 aircraft, along with training for pilots, and training in windshear avoidance and escape for pilots of Part 135 operations.[58] Many airlines include simulator windshear training to alert flight crews to the indications of incipient windshear and to help them in controlling the aircraft so as to retain sufficient power during escape/avoidance maneuvering.

Because of the many subtleties in the use of cockpit weather sensors, and because of their inherent limitations, adequate, appropriate training is essential for their proper use. The training must involve instruction in the actual use of the equipment, as well as recognition of visual cues for dangerous weather conditions, such as windshear. FAA sponsored joint industry/government development of a windshear training program, called Windshear Training Aid. Completed in February 1987, the program represents the consensus of airlines, manufacturers, pilots, the research community, and government regulatory and safety agencies. The training program is part of the Integrated FAA Wind Shear Program Plan.[59]

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[58] 52 *Federal Register* 20559-20571 (June 1, 1987).

[59] E.A. Kupcis, "Windshear Training Aid," *Boeing Airliner*, July-September 1987, pp. 2-7.

Although windshear training is receiving increased attention at this time, training programs for use of weather information in the cockpit are believed by some experts to be inadequate.[60] In particular, many airlines provide minimal pilot training in the use of information such as that available from airborne weather radar. The situation has become more acute as airlines have cut staff and are less equipped to offer professional meteorological help.

National Weather Service

FAA, the National Weather Service (NWS), and some commercial organizations are involved with detecting weather, interpreting the information, and communicating the information to pilots and FAA field personnel. The NWS Aviation Services Branch is in charge of providing aviation weather information, and relies on FAA to stipulate the requirements for the information. Airlines, as well as FAA, use information provided by NWS for functions such as pilot briefings.

NWS operates ground sensors on airports (FAA also operates ground sensors on airports; in fact, more than NWS),[61] Geostationary Operational Environmental Satellites (GOES), upper-air sounding devices, and Weather Service Radars to sense weather for aviation and other users. NWS meteorologists interpret information from the sensors to produce products specifically tailored to aviation needs, such as Terminal Forecasts.

FAA operates Flight Service Stations (FSSs) to provide preflight briefings and in-flight weather information over VHF radio primarily to general aviation pilots, although Part 135 operators use FSSs as well. FSSs are staffed by FAA personnel who are not meteorologists, but who are specifically trained and have access to information from NWS sources, including GOES data, surface observations, and forecasts produced by NWS meteorologists.

Air Traffic Control Role

Air traffic controllers in ARTCCs, TRACONs, and airport towers are an important source of weather information to commercial aviation pilots, although when controllers are busy managing crowded airspace, significant delays occur before weather information is relayed to pilots. Controllers currently receive weather information from pilots in the form of pilot reports, from the weather channel of the en route surveillance radar (and in the future, from ASR-9), from the Center Weather Service Unit (CWSU) meteorologist located in each ARTCC, from NWS products supplied directly to them, from direct observation (in the case of tower cab controllers), and from FAA's Low Level Windshear Alert System (LLWAS). The communication links between the sources of weather information and controllers are often primitive; CWSU meteorologists sometimes leave their CWSU stations to deliver messages by hand to controllers.

Automation and digital air/ground communications could reduce or eliminate the controller's role in the process of providing weather information to pilots. However, controllers themselves need to be aware of bad weather to anticipate when pilots are likely to ask for deviations from their initial flight plans, so they can manage the traffic situation better. Traffic management controllers at ARTCCs and, nationally, Central Flow Control controllers need accurate weather information, so they can adjust traffic flows to the capacity of the system.

LLWAS is a system that employs wind vanes and anemometers in the vicinity of an airport to generate windshear alerts for tower controllers, who are supposed to broadcast the information to pilots under their control. LLWAS was developed in the 1970s before windshear phenomena were understood very well, and is optimized for detecting gust fronts, which are relatively harmless to large aircraft, rather than for detection of deadly microbursts. LLWAS misses some microbursts because the sensors are too widely spaced, produces many false alarms, and its alarms are not timely enough to track the rapid buildup and decay of most microbursts.[62]

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[60] John McCarthy, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings—OTA Workshop on Technology in Commercial Aviation Safety," unpublished typescript, July 1, 1987, pp. 169-170.

[61] Robert E. Brown, deputy director, Program Engineering Service, Federal Aviation Administration, letter to OTA, n.d.

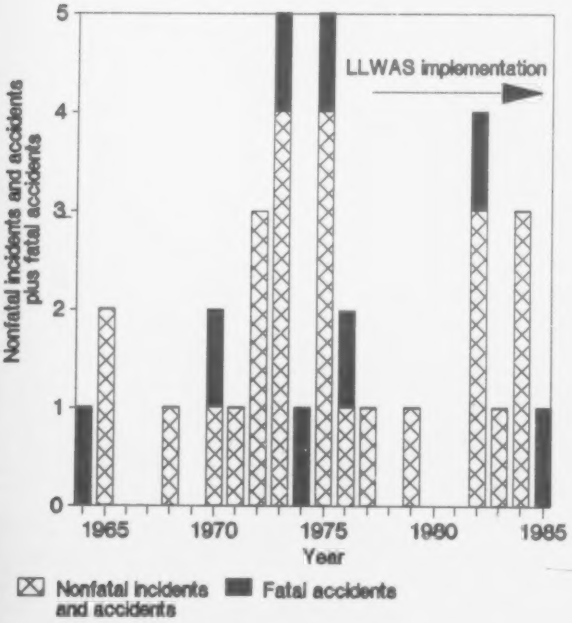
[62] John McCarthy, National Center for Atmospheric Research, "To Improve the Detection of Hazardous Aviation Weather," testimony before U.S. Congress, House Committee on Public Works and Transportation, Aviation Subcommittee, Oct. 2 and 30, 1985, pp. 23-61.

Figure 7-6 plots windshear accidents and incidents for transport category aircraft by year since 1964; no statistical evidence shows that LLWAS has reduced the rate of incidence of windshear-caused accidents.

Weather Research and Development

R&D into windshear sensors falls into two categories, ground-based and airborne, and both categories are being pursued by FAA as part of its Integrated Wind Shear Program Plan.[63] Two ground-based windshear detection technologies are being developed: an enhanced version of LLWAS and Terminal Doppler Weather Radar (TDWR). Enhanced LLWAS includes more sensors at each airport and software changes to allow better and more timely detection of microbursts. However even enhanced LLWAS cannot detect microbursts before they hit the ground, which may be too late. TDWR may permit early detection of microbursts, and could be more reliable than enhanced LLWAS, although obstructions on or near the airport surface would limit the coverage of TDWR. One major technological challenge is to develop and validate computer algorithms for automatic detection of microbursts with TDWR.

Figure 7-6.—Windshear Accidents and Incidents Before and After LLWAS Implementation



KEY: LLWAS = Low Level Windshear Alert System.

SOURCE: 52 *Federal Register* 20562-20563 (June 1, 1987); and Federal Aviation Administration, "Integrated FAA Wind Shear Program Plan," DOT/FAA/DL-8711, April 1987.

Originally FAA planned to deploy TDWR at about 100 airports, but the Office of Management and Budget recently restricted the number to 44, based on cost-benefit analysis.[64] An integrated sensor system consisting of both enhanced LLWAS and TDWR may be the best choice at airports where the windshear threat justifies deploying both, but the problem of integrating the sensors to produce a single message to pilots and controllers needs to be solved. Another challenge is to develop a message format and a reliable means of communication of the information to pilots. A message format developed in 1987 by a users' working group has been used at Denver with the enhanced LLWAS, and has been found satisfactory for the TDWR operational demonstration scheduled for summer 1988. Development of ground-based windshear detection technology that is less expensive than TDWR, but more capable than enhanced LLWAS, would help alleviate microburst risk at smaller airports with increasing traffic levels.

Airborne windshear sensors are in a more preliminary stage of development than the ground-based sensors. FAA is underwriting the basic technical and scientific developments in airborne systems to the point where technologies can be developed and marketed commercially. Airborne sensors do not have the coverage limitations of ground sensors, do not rely on a ground-to-air communications link, and provide advance warning. Microwave radar and light detection and ranging technologies are currently undergoing assessment by FAA and a consortia of manufacturers, and at least two companies are independently investigating look-ahead infrared temperature sensors for microburst detection.[65]

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[63] U.S. Department of Transportation, Federal Aviation Administration, *Integrated FAA Wind Shear Program Plan* (Springfield, VA: National Technical Information Service, April 1987).

[64] Arthur L. Hansen, manager, Weather Radar Staff, Federal Aviation Administration, personal communication, Mar. 3, 1988.

[65] Herb Schlickenmaier, project manager, Airborne Windshear Detection and Avoidance, Federal Aviation Administration, personal communication, Nov. 3, 1987.

FAA, NWS, and the Department of Defense are participating in a joint program, called NEXRAD (next generation weather radar), to upgrade the current system of radars used to map rainfall levels across the United States. NEXRAD is planned to replace the current network of NWS radars, and to provide both reflectivity and velocity dispersion information for determination of turbulence levels. NEXRADs will be sited temporarily at airports where windshear is an especially serious threat to serve as interim terminal weather radars before TDWR is introduced. The issue of how to present NEXRAD information to pilots—through controllers or as a graphical product—has not yet been resolved. Air traffic controllers will receive graphical NEXRAD information.

Automated systems to collect other weather information in the terminal area are being developed by both FAA and NWS. The replacement of human observers by these systems is currently controversial, and message formatting and communication of the information to pilots are unresolved issues. NWS plans to upgrade its capabilities for providing information and making forecasts include replacing the current data analysis and distribution system with a sophisticated network of computing, communications, and display capabilities. Another developing technology is the profiler system to replace current balloon technology for upper atmospheric measurements; the results for aviation include more accurate amd timely winds information, hazardous weather warnings, and forecasts for better airspace planning.

Some airlines have meteorology departments that handle preflight briefings, and all airlines are required to have dispatch organizations that transmit weather information to pilots over the company radio system or over ACARS.[66] Some pilots utilize publicly televised weather programs such as "A.M. Weather," or newspapers to obtain weather information.

Improving weather information available to pilots requires better training for NWS forecasters and observers, air traffic controllers, and flight service station specialists in use of weather information and observing weather. Moreover, as new weather sensor technologies are fielded, training for users of the information must be stepped up to ensure safe air travel.

LIABILITY ISSUES

Liability issues haunt aviation safety because an accident that implicates a safety technology or training program could cost a manufacturer or airline more than it is worthwhile to risk. For example, Boeing nearly backed out of its participation in the Windshear Training Aid program over liability concerns, until the Secretary of Transportation intervened and convinced the manufacturer to continue.[67] The industry-wide endorsement of the results of the program suggest that a valuable product for making commercial aviation safer would have been lost if the project had been abandoned. No other commercial aviation safety technologies or programs have been identified which are in danger of extinction because of liability, but new industry initiatives in the future could be impeded. Liability has had a large impact on the GA industry; while tort actions have produced improvements in areas such as handbooks and crash survivability, the GA industry is in severe financial straits.

CONCLUSIONS AND POLICY OPTIONS

While further safety improvements through technology will come at relatively high cost, several technology areas show real promise for improving the current level of safety even as demands increase on the air system.

Some ATC facilities are already severely taxed because of inadequate equipment and unmet controller training needs. Installation of Host computers at en route centers was a major step in bringing up the capabilities of the centers to meet traffic demands.

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[66] 14 CFR 121.599 and 601 (Jan. 1, 1987).

[67] Edgars A. Kupcis, New Product Development, Boeing Commercial Airplane Co., personal communication, Aug. 4, 1987.

However, equipment at en route centers, TRACONS, and airport tower cabs is old and difficult to replace; furthermore, the centers have limited expansion capabilities to handle more radars and controller positions. AAS will upgrade capabilities at air traffic facilities, but the system will not be ready in time to head off capacity problems before the mid- to late-1990s.

TRACONs and tower cabs that control traffic around busy airports will face even more responsibilities in the near future when broadened Mode C transponder requirements become effective. Furthermore, many TRACONs would require capacity enhancement to include the Mode C Intruder Alert function. Currently, the New York TRACON equipment is being upgraded for increased capacity, Mode C Intruder Alert, and better displays. **OTA finds that other TRACONs will need additional computer capacity to handle expected increases in transponder traffic levels without performance degradation, and still more capacity if the Mode C Intruder Alert feature is included.** Funds for increasing equipment capacity at TRACONs are included in FAA's fiscal year 1989 budget request. The Mode C Intruder Alert, which will be used at all ARTCCs, could be used at TRACONs as well, but needs analysis and testing to ensure that its false alarm rate is acceptable. Installation of the Mode C Intruder Alert at TRACONs is expected to be part of the 1988 version of the NAS Plan.

While recent legislation will require broader carriage of Mode C transponders by GA aircraft, some aircraft will still not carry Mode C transponders. An option is to continue to increase altitude-encoding transponder requirements, concurrent with increased ATC equipment capabilities and personnel, to guard against accidental incursions into airspace where radar coverage is provided and to provide the maximum protection through TCAS.

Automation tools for controllers at all facilities—airport tower cabs, TRACONs, ARTCCs, and the Central Flow Control Facility—could assist in the safe handling of higher levels of traffic and reduce pressures on air traffic controllers. In particular, terminal automation development is a potential area for improvement prior to AAS. While terminal automation development has not previously been well funded, additional funding is being sought by FAA for fiscal year 1989. **For the longer term, ATC problems may worsen as traffic levels increase unless the infrastructure of the ATC system is upgraded.** AAS is FAA's long-term program to avert ATC problems. **In the interim, before AAS is fully implemented, support to FAA for analysis to identify emerging operational problems and to establish parameters for solutions to the problems would help facilitate adequate ATC system capabilities as the air transportation system evolves.** Timely, cost-effective solutions to ATC problems must include both technological changes and support for related personnel needs. (See chapter 3 for more discussion of ATC personnel problems.) AERA offers potential long-term benefits for en route controllers through automation, but more work is needed to understand both the system safety and efficiency implications of AERA to clarify whether AERA will facilitate safe control of higher traffic levels.

Weather is a contributing factor in many aircraft accidents, and sensors such as TDWR hold great promise for improving safety through rapid detection of dangerous weather. The high cost of TDWR, however, may preclude its use at all but the largest airports, so other lower cost technologies for microburst detection (in addition to enhanced LLWAS) merit further examination. **OTA finds that improved training for pilots in use of weather information available in the cockpit, and R&D to develop message formats and workable air/ground communications for weather information, are at least as important as weather sensor development for improving aviation safety.**

Current air/ground communications are not always adequate to support the needs of pilots for both real-time ATC and real-time weather information. Providing ATC information to ensure separation between aircraft and issuing safety alerts are the controllers' first priorities, and controllers sometimes do not have time to transmit weather information to pilots or are distracted from transmitting information by more urgent demands to separate traffic. **For the near term, better pilot training in use of information from on-board weather radar and from visual observations can compensate somewhat for occasional lack of weather information from controllers.** The FAA's Windshear

Training Aid program, developed cooperatively with industry, has features that are a step in this direction. **For the longer term, automation and development of digital air/ground data links can eventually remove controllers from the process of relaying weather information to pilots and can potentially reduce controller workload for ATC messages.** The Mode S data link can be integrated with commercial data links to produce a very reliable system with excellent coverage and capacity. However, in the past, digital communications have been relegated by FAA to the distant future, and commitment is needed to replace the current analog voice system. **OTA concludes that R&D efforts on data link services, human factors, and system integration have a potentially high payoff for efficiency as well as safety.** Both FAA and NASA (which already has personnel, facilities, and equipment to do some of this R&D) have begun work in this area.

TCAS has taken a long time to reach its present stage of readiness for limited installation testing, and whether TCAS introduces unexpected ATC problems and human factors questions remains to be seen. Not all countries are satisfied with TCAS, and requiring its use in the United States will not guarantee its eventual use everywhere. None of these issues appears to be a crucial stumbling block to TCAS.

Although the United States has had few recent fatalities from collisions on the airport surface, a number of nonfatal collisions and close calls have occurred. As air traffic levels increase, the probability of a disastrous ground collision will increase, lacking compensatory measures. The ASDE-3 radar, currently under development, is one such measure, but other means to improve ground collision safety include improved signs on the airport surface, control lights at entrances to active runways, and more vigilance by pilots during taxi operations. **Congress may wish to encourage FAA to expedite increased ground collision safety through technological, procedural, and training approaches, as well as through ASDE-3 development.** Short-term R&D to improve sign symbology could provide the basis for consistent standards for taxiway and runway signs at all U.S. airports. If current tests are successful, stop/go bar lights and signal lights could be installed at entrances to major runways to augment runway clearances from ground controllers. Additional controllers for airport towers would be needed to operate the lights. Procedural rules could be changed to require that both pilots and co-pilots be free of other work while taxiing, and training for pilots and controllers on preventing runway incursions could be increased.

Air traffic controllers at some en route facilities now receive site-specific training at the FAA Academy in Oklahoma City, because of inadequate resources at the en route facilities. **OTA finds that improved simulation training for air traffic controllers could lead to more cost-effective ATC training, both now and in the future, when further automation is introduced.**

FAA has begun development of system-wide capacity models (NASPAC) to take into account traffic flows between airports. **Continued emphasis on analytical modeling to better understand capacity of the air traffic system would help FAA assume a leadership position in the future when difficult issues regarding capacity, safety, noise, and airline scheduling arise.**

The NAS Plan has suffered because requirements for its technologies have changed since the Plan was created in 1981. FAA, recognizing the emergence of important near-term needs, has established an interim support program. However, FAA has done relatively little near-term or far-term research to support NAS developments. NASPAC and other operations research and analysis efforts could help FAA identify emerging ATC problems and parameters for solutions to the problems. An area for further investigation is the use of modern prototyping and test bed technology to help FAA evaluate alternative technological and operational solutions in a realistic way that encourages innovation and timely fielding of technology.

Chapter 8

Aircraft Technologies

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Photo credit: Boeing Commercial Airplane Co.

Horizontal situation display for the cockpit

CONTENTS

Page

Regulation of Aircraft Technologies 165

Airworthiness 166

Equipment Certification Process 167

Simulators for Pilot and Mechanic Training 169

The Future of Commercial Aircraft Technology 170

Cockpit Technologies 170

Advanced Materials for Aircraft 171

New Aircraft Engine Types 172

Technologies and Training for Icing 174

Crash and Fire Safety Technologies 175

Conclusions and Policy Options 175

Figure

Figure *Page*

8-1. Controlled Flight Into Terrain: Descent and Approach Phase of Flight 166

Chapter 8

Aircraft Technologies

Technological advances have generated new types of sophisticated and complex commercial aircraft. Functions once performed by pilots using information provided by electromechanical displays are now performed automatically, with information for the pilot presented on electronic displays. New fly-by-wire concepts sever the mechanical connection between pilot and the aircraft wing and tail. Dozens of electronic devices monitor and control aircraft components, and newer types of aircraft provide pilots or automated control devices such as computers and actuators with enormous quantities of information. Simultaneously, at the other extreme, many airlines are operating older types of aircraft, finding the high cost of new equipment prohibitive. Thus, the commercial aviation industry uses a variety of aircraft technologies of various ages and levels of sophistication—all regulated by the Federal Government to assure the safety of the flying public.

This chapter examines the Federal Aviation Administration (FAA) rulemaking and enforcement activities for new aircraft technologies, including standardization across FAA directorates, technical expertise and personnel levels, and inspector training. Because the future will bring new cockpit and engine technologies and advanced materials, high-speed aircraft, and vertical and short takeoff and landing aircraft, the implications of such technologies for safety and regulatory activities are also reviewed.

REGULATION OF AIRCRAFT TECHNOLOGIES

FAA rulemaking in areas of technology is often controversial; parts of industry have, on occasion, claimed that FAA has forced the development of technology by proposing or suggesting a rule, often at the urging of Congress or the National Transportation Safety Board. However, the point at which a new technology is ready for implementation is quite subjective. For instance, anti-misting kerosene fuel was given a widely publicized crash test in 1984 with direct inference that a rule requiring its use was forthcoming. The test did not go as planned, at least in part, because the aircraft, controlled from the ground, hit the target for the controlled crash at an angle. An engine was damaged and exploded, igniting escaping fuel and creating an inferno. Temperatures within the cabin, however, remained within the survivable range. The failed crash test reinforced other evidence that, despite previous successes with smaller scale tests, anti-misting kerosene was still a developmental substance, and further research was needed. Another example is flammability standards for cabin materials. An FAA rule requires that cabin materials in transport category airplanes meet test criteria based on heat release as a measure of flammability, with two steps to incorporation—August 1988 and August 1990.[1] Some industry sources have argued that materials meeting the criteria did not exist, at least at the time of the rulemaking;[2] in any case, meeting the criteria will surely be costly to airlines and manufacturers. Concerns have also arisen about the applicability of the required test criteria, since they do not explicitly include smoke; FAA's position is that heat release alone is an adequate criterion because of a correlation between heat release and smoke.

Congress plays a role in regulating aircraft technologies through its oversight of FAA and hearings are often used to focus attention on regulatory issues that are important to Congress. Congress can also pass laws that force technology requirements. One example is the recent legislation, discussed in chapter 7, requiring collision avoidance equipment in commercial aircraft and expanding Mode C transponder requirements for general aviation (GA). Congress also urged rapid completion of regulations requiring the Ground Proximity Warning System

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[1] 51 *Federal Register* 26206 (July 21, 1987).

[2] 51 *Federal Register* 26166 (July 21, 1987).

(GPWS). Although GPWS suffered from false-alarm problems early on, it has demonstrably improved safety for approach and descent phases of flight (see figure 8-1).

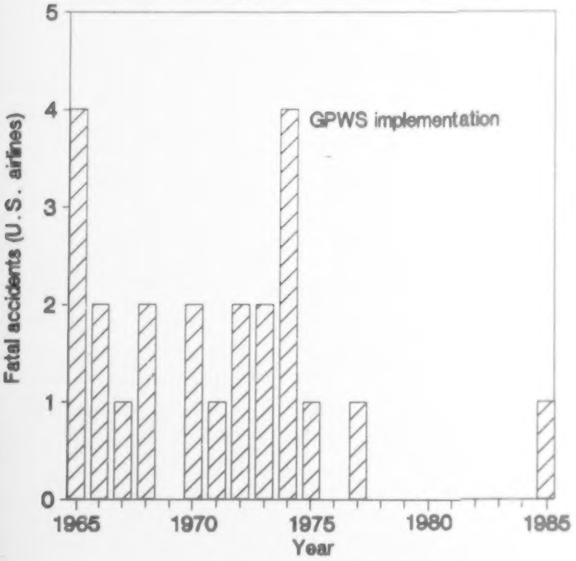
Airworthiness

Government responsibilities for equipment airworthiness include development and administration of safety standards for aircraft, engines, propellors, and appliances such as avionics. Certification of aircraft is at three levels: type, production, and original. Type certification is FAA approval of the design of an aircraft, production certification is approval of the quality control system for production, and the original certification process is the granting of approvals of the first and subsequent aircraft off the assembly line.[3] In cases where the FAA Administrator finds that airworthiness regulations do not contain adequate or appropriate safety standards for an aircraft, aircraft engine, or propellor because of a novel or unusual design feature, he may prescribe special conditions for the product to allow its certification.[4] FAA is also responsible for noise and emission level certification of aircraft.

Photo credit: Boeing Commercial Airplane Co.

Prior to their use, commercial aircraft undergo extensive testing, such as this water spray test of the Boeing 767-200.

Figure 8-1.—Controlled Flight Into Terrain: Descent and Approach Phases of Flight



KEY: GPWS = Ground Proximity Warning System.

SOURCE: Office of Technology Assessment, adapted from L.G. Lautman and P.L. Gallimore, "Controlling the Crew Caused Accident," Boeing Commercial Aircraft Co., May 1987.

FAA rarely has the personnel or the specific technical expertise to certify an aircraft type without assistance from the manufacturer. FAA relies heavily on Designated Engineering Representatives (DERs), who are experienced engineers employed and paid by the manufacturer, but supervised by FAA, to help in the certification process. DERs provide opportunity for conflicts of interest, although the professionalism of the DERs and supervision by FAA mitigate against this.[5] Their experience in working with FAA regulations often makes DERs prized personnel for manufacturers.[6]

However, to ensure that certification requirements are adequately applied, FAA requires technical expertise on its staff to provide oversight for DERs. The largest pool of such expertise is in the ranks of engineers at the manufacturers, and FAA has had difficulty in attracting highly qualified and experienced engineers to work in certification in recent years. Some contend that this is due to the pay scale for engineers at FAA which has not kept up with industry, and because of limited career development opportunities at FAA.[7] The pay scale for certification engineers applies to engineers at the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), and other Federal organizations, as well. FAA maintains that broader systems knowledge is required of its certification engineers than of engineers at the other organizations and that FAA certification engineers could be on a higher pay scale.[8] FAA employs about 10 National Resource Specialists, who are experts in particular areas, at a higher salary level.

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[3] U.S. Department of Transportation, Federal Aviation Administration, "Aircraft Certification Safety Regulatory Program Description," briefing document, n.d.

[4] 14 CFR 21.16 (Jan. 1, 1987).

[5] National Research Council, *Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft* (Washington, DC: National Academy of Sciences, 1980), pp. 29-31.

[6] William Ashworth, office manager, Seattle Aircraft Certification Office, Federal Aviation Administration, personal communication, Aug. 4, 1987.

FAA's control over type certification is shared by four of its regional offices, a decentralized organization that lends itself to internal FAA disagreements over regulatory actions. An example is the Boeing request to screen off two of the 10 exit doors on 747s, discussed in chapter 3.

The FAA Associate Administrator for Aviation Standards has recognized that the certification program is not standardized across directorates, is unable to keep up with technical developments because of a shortage of expertise, and has human relations problems and training limitations for certification personnel. Project SMART is now under way to develop a master plan to address these problems and upgrade the aircraft certification regulatory program. So far, a job task analysis and management analysis for certification have been started. The knowledge gained from Project SMART has already begun to benefit the national training program, job design and restructuring, and other areas through its recommendations for improvement. Project SMART has not yet received project funding, but is supported by miscellaneous funds from other projects.[9]

Both Parts 121 and 135 prescribe minimum airplane instrument and equipment requirements,[10] and the regulations contain the specification and installation requirements for instruments and equipment. The major categories of instruments and equipment specified in the regulations are: flight and navigational equipment; engine instruments; emergency equipment; seats, safety belts, and shoulder harnesses; public address and crewmember interphone systems; special instruments for operations at night and under instrument flight rules or over-the-top conditions; oxygen and other protective breathing equipment; radio equipment; weather detection equipment; flight and cockpit voice recorders; and ground proximity warning devices. Carriers operating under Parts 121 and 135 are prohibited from using airplanes unless certain instruments or pieces of equipment, contained in a minimum equipment list for the aircraft type, are operable. However, there are numerous differences between the Part 121 and Part 135 instrument and equipment regulations. While many of these inconsistencies exist because of differing design and performance capabilities of large and small airplanes, certain pieces of equipment required for Part 121 operations have been intentionally excluded from Part 135, primarily for economic reasons that predate deregulation. These inconsistencies have caused concern since deregulation for several fundamental reasons. First, for some routes, Part 135 operations have replaced Part 121 operations. Second, the intent of Congress was to not allow any diminution of safety because of deregulation. Third, code-sharing arrangements have produced cases where passengers are not aware that they will be flying with a Part 135 operator when they buy a ticket from a major carrier. Regulatory initiatives are under way to address flight and cockpit voice recorders, ground proximity warning devices, and crew interphone systems for Part 135 operations.[11]

Equipment Certification Process

Aircraft engines and propellors are subject to the same certification process as aircraft. Appliances, such as avionics, are certified through the development of Technical Standard Orders. The technical basis for appliance certification is often the work of standards organizations such as the Radio Technical Commission for Aeronautics (RTCA) and the Society of Automotive Engineers (SAE). RTCA covers communications systems, while SAE covers a wide variety of systems such as landing gear, oxygen equipment, aircraft instruments, and many others. RTCA and SAE form committees of industry and government representatives to examine standards for aircraft appliances, and produce documents which represent the consensus of the group. FAA is under no legal obligation to use these documents, but frequently utilizes them because of the technical knowledge they embody and because they are the products of agreement between many disparate groups.[12]

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[7] Ibid.

[8] Dennis H. Piotrowski, program manager, Office of Airworthiness, Federal Aviation Administration, personal communication, Sept. 29, 1987.

[9] Ibid.

[10] 14 CFR 121, Subpart K and 14 CFR 135, Subpart C (Jan. 1, 1987).

[11] Examples of other differences include: 1) regulations for protective breathing equipment for flight crewmembers in pressurized aircraft, required under Part 121, are not included in Part 135; and 2) although airborne weather radar equipment is required for large transport category airplanes (20 seats or more) under Parts 121 and 135, multiengine aircraft with 10 seats or more are required to have airborne thunderstorm detection equipment only.

Maintenance regulations for operations under Part 121 and for operations using aircraft with 10 or more passenger seats under Part 135 are similar; separate maintenance requirements for Part 135 operations using aircraft with 9 seats or fewer are described below.[13] Certificate holders, who are primarily responsible for the airworthiness of their aircraft, are required to establish maintenance organizations and programs, or arrange to have some or all of the work performed by qualified outside entities.[14]

The operations specifications for each carrier describe the maintenance and inspection requirements that must be met. Typically, these activities include: routine aircraft inspections, tests, and servicing performed at prescribed intervals; scheduled maintenance tasks, such as replacement of life-limited items and nondestructive testing; unscheduled maintenance activities generated by inspections, flight crew reports, or other analyses; specific engine, propeller, and appliance repair and overhaul tasks; and major structural inspections and airframe overhauls. Required inspection items, work elements that could endanger the safe operation of an aircraft if improperly done, are also specified. All maintenance activities must be conducted in accordance with performance standards specified in 14 CFR 43, and records must be kept of all work performed on an aircraft.

Parts 121 and 135 regulations require that maintenance organizations be adequate to perform all work and required inspections; and that inspection and maintenance functions are kept separate below the administrative control level. Mechanics and repairmen employed by certificated carriers must meet minimum certification requirements contained in 14 CFR 65. In addition, carriers are required to prepare detailed manuals for employees prescribing methods, standards, and procedures for all maintenance. Some airlines use the job cards of the aircraft manufacturer's maintenance manual without modification for their own program; this saves the airline the cost of having to develop its own system.[15] Airlines may not perform major repairs on airplanes unless so authorized by FAA,[16] but there are ambiguities in the definition of "major repair."[17] Airlines are required to establish training programs to inform maintenance and inspection personnel about procedures, techniques, and new equipment and to develop an internal audit system to ensure quality control.

Although work limits have not been prescribed for maintenance personnel under Part 121, existing regulations require that they be relieved from duty for at least 24 consecutive hours during any 7 consecutive days or an equivalent period within any calendar month. A similar provision has not been included in the Part 135 regulations.[18]

Maintenance requirements for Part 135 operations using aircraft with nine seats or fewer are less extensive.[19] These operators are permitted to follow the maintenance requirements in 14 CFR 91 for GA aircraft, unless FAA determines that a more rigorous program is necessary. In these instances, operations specifications are amended to require a program that contains: instructions and procedures for aircraft inspections, specifying parts and sections of airframes, engines, propellers, rotors, and appliances; schedules for performance of aircraft inspections in terms of time in service, calendar time, or number of system operations; and instructions and procedures for recording discrepancies found during inspections, corrections, or maintenance deferrals.

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[12] William G. Osmun, *The Authority of Agreement: A History of RTCA* (Washington, DC: Radio Technical Commission for Aeronautics, 1985).

[13] 14 CFR 121, Subpart L and 14 CFR 135, Subpart J (Jan. 1, 1987).

[14] A carrier authorized by the Federal Aviation Administration to perform all maintenance and inspection activities required under Part 121 or 135 on its own aircraft or for other carriers or operators does so under a Continuous Airworthiness Maintenance Program. See U.S. Department of Transportation, Federal Aviation Administration, "Continuous Airworthiness Maintenance Programs," Advisory Circular 120-16C, Aug. 8, 1980.

[15] David Sayre, supervisor, Maintenance and Ground Systems, Boeing Commercial Airplane Co., personal communication, Aug. 3, 1987.

[16] 14 CFR ch. 1 SFAR-36 (Jan. 1, 1987), pp. 288-290.

[17] William C. Keil, USAir and Melvin C. Beard, Federal Aviation Administration, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings—OTA Workshop on Technology in Commercial Aviation Safety," unpublished typescript, July 1, 1987, pp. 227-229.

[18] 14 CFR 121.377 (Jan. 1, 1987).

[19] 14 CFR 135.411 (Jan. 1, 1987).

Principal Maintenance Inspectors (PMIs), who inspect airlines' maintenance operations, are stationed at FAA field offices. PMIs also participate with factory maintenance specialists assigned to the aircraft manufacturer in an FAA review board to develop minimum maintenance requirements for aircraft types. Questions have been raised over the adequacy of FAA surveillance of airline operations and the capabilities of inspectors to monitor maintenance programs and approve waivers or deviations from operating specifications. For further discussion of the adequacy of the number of FAA inspectors and FAA training programs for inspectors, see chapters 3 and 5.

An aircraft or part manufacturer may send airlines a service bulletin recommending a change in a configuration or an inspection or maintenance procedure to be carried out by the maintenance department. More urgent service bulletins, called alert service bulletins, usually evolve into Airworthiness Directives (ADs) issued by FAA, which require changes that must be made to retain aircraft certification. Sometimes extensive negotiation is required between an airline and FAA to ensure that an airline receives credit for promptly responding to a service bulletin, prior to the issuing of the AD.[20] In other cases, however, FAA and a manufacturer have utilized the efforts of an operator, incorporating the procedures into a service bulletin and AD.[21]

Simulators for Pilot and Mechanic Training

Simulators are currently used for initial, transition, and upgrade training, recurrent training, and proficiency checking of pilots. The efficiency, speed, safety, and low cost of simulator training compared to training in aircraft makes it attractive to airlines, as they order new aircraft and new aircraft types and recruit and train pilots. Simulators become more important from a safety standpoint as airlines must hire less experienced pilots, because simulators can provide experience in dealing with many safety-critical situations in a short time.

In addition to the full-motion, full-visual training simulators provide, a substantial amount of training is done in fixed-base cockpit training devices with no simulated scenes outside the cockpit. Personal computers (PCs) with graphics and touch-screen capabilities are also used extensively for aircraft systems and avionics training, typically one system at a time. The fixed-based cockpit training devices and PC-based training aids save precious time in the expensive full-motion simulators.

In general, a full-motion, full-vision simulator with a complete mock-up of the cockpit and avionics costs on the order of $10 million, regardless of aircraft type. Because of this high cost, airlines that buy simulators usually intend to sell simulation services to others, except for large airlines that have many aircraft of the same type.[22] Some airlines also send pilots to aircraft manufacturers for simulator training.

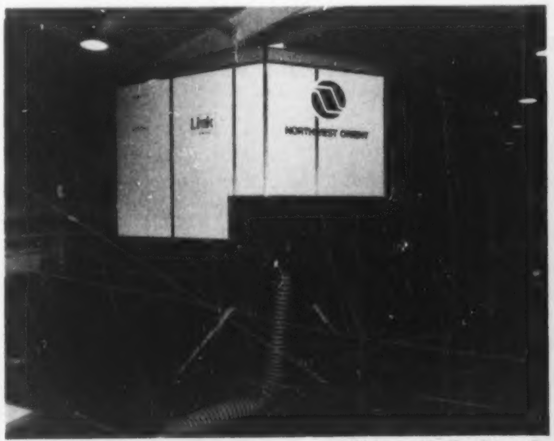

Photo credit: The Singer Co.

The exterior of a full-motion pilot training simulator

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[20] William C. Keil, staff director, Engineering and Quality Assurance, USAir, Inc., personal communication, Oct. 14, 1987.

[21] David Lotterer, Air Transport Association of America, letter to OTA, Jan. 7, 1988.

[22] Mark Lambert, "Simulator Makers Face New Market Conditions," *Interavia*, vol. 42, January 1987, pp. 75-76.

Part 121 operators use full-motion simulators extensively, but Part 135 operators generally do not, because of the prohibitively high cost of the simulators. Federal regulations spell out requirements for Part 121 operators on simulator capabilities and what they can be used for, but are not specific on simulator use by Part 135 operators.[23] However, FAA recently released advisory circulars which delineate Part 135 requirements for advanced training devices (ATDs, which are essentially simulators without motion or visual simulation), and state where ATDs may be used instead of flight in an actual aircraft for training and testing.[24] The regional airlines have been arguing for use of ATDs since 1984.[25]

Simulators for aircraft maintenance personnel are used to provide systems overviews and demonstrations, and for practice at equipment analysis, fault reporting, and diagnosis. Computer-aided training using microprocessors is also used at certain stages of training.[26]

THE FUTURE OF COMMERCIAL AIRCRAFT TECHNOLOGY

The future will bring changes in commercial aviation technology, including further development and use of electronic systems for sensing the environment and control of the aircraft, new aircraft engine types, use of composite materials in aircraft construction, and new types of aircraft such as tilt-rotor and supersonic/hypersonic aircraft. Most of the changes will not be motivated primarily by concern for safety, but by the desire for efficiency and speed of travel. Significant changes are also likely in the air traffic control (ATC) system, bringing more automation, automatic decisionmaking, and methods of dealing with limited airport capacity. The changing state of technology and the airspace system require continuous safety oversight by government and industry, so that efficiency and speed are not gained at the expense of safety. Advanced technologies will present significant challenges to the government in terms of certification and flight safety. In particular, as automated systems take over more tasks, including decisionmaking, that are now performed by humans, the interaction between humans and advanced equipment will need special attention.

Cockpit Technologies

The current trends in cockpit technology are toward more automation and advanced displays for pilots, driven primarily by the push for two-pilot cockpits to save airlines the cost of a third crewmember. More information is available to pilots from new sources, and new systems can provide quick, automatic reaction within safe aircraft performance limits to events such as windshear encounters. Moreover, new technologies offer increased equipment reliability, trouble-shooting capability, and reduced weight, compared with older technologies. For all these reasons, the trends will continue into the forseeable future.

Some areas of current research and development (R&D) include liquid crystal flat-panel displays, head-up displays, voice recognition systems, fly-by-wire and fly-by-light, and artificial intelligence (AI) applications. Liquid crystal displays offer the potential for high luminance and resolution using little power. Powered by lithium-cell batteries, such displays could be useful as standbys in case of engine or power system failure. However, the displays are very temperature sensitive and have a slow transition time, weaknesses that are subjects of current R&D.[27]

Fly-by-wire technology is included on the Concorde, the Boeing 757 with the Pratt and Whitney 2037 engine, and the Airbus 320. Fly-by-light technology may appear on the Boeing 7J7, if Boeing completes its development of that airplane. These technologies replace most of the mechanical links from the pilot's controls to the wings and tail by electrical wire or optical fibers. Fly-by-wire and fly-by-light save weight, reduce maintenance, and eliminate the variabilities of hydromechanical systems, thereby making airplanes easier to operate and reducing the rate of increase of aircraft operating costs. Furthermore, computers can analyze information about the behavior of the airplane and, through the fly-by-wire or fly-by-light mechanisms, physically prevent a dangerous maneuver. Currently, research is taking place in the areas of stick configuration, stick "feel," and how to handle cases where both pilots use the controls simultaneously.[28]

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[23] 14 CFR, Ch. 1, Part 121, Appendix H (Jan. 1, 1987).

[24] U.S. Department of Transportation, Federal Aviation Administration, "Advanced Training Devices (Airplane Only) Evaluation and Qualification," Advisory Circular No. 120-45, May 11, 1987.

[25] Richard L. Collie, Technical Services, Regional Airline Association, personal communication, Aug. 17, 1987.

[26] R. O. Jollie, "Digital Avionics Training," *Boeing Airliner*, April-June 1987, p. 21.

[27] John T. Merrifield, "Transport Manufacturers Press for Automated Cockpits," *Aviation Week & Space Technology*, Mar. 10, 1986, p. 247.

Most research on AI applications for the cockpit takes place in a military context. For example, the Defense Advanced Research Projects Agency sponsors the Pilot's Associate program to evaluate and demonstrate the utility of AI and expert systems techniques for military applications. Applications under examination include monitoring aircraft systems (i.e., the role of the flight engineer), mission planning and replanning, external situation assessment, and devising optimum strategies to deal with external threats.[29] NASA-Ames is also pursuing a program to optimize the guidance and control of aircraft (including ATC) using AI techniques. Although the program may have civil applications, its basic thrust is toward military aircraft.[30] Potentially, AI techniques could find application to civil aircraft in monitoring aircraft systems and dealing with complex weather information.

Advanced Materials for Aircraft

Many new types of advanced materials may be used in future aircraft. Composite materials are attractive because of their strength/stiffness properties and their lighter weight and corrosion resistance. Other advanced materials include aluminum alloys, advanced ceramics, special high-strength steels, titanium/aluminum alloys, and rigid-rod polymers, which consist of small rods of high-strength polymer embedded in a tough polymer matrix. Improved material coatings may also be used in stressful environments, such as for turbine engine blades.[31]

Processing and assembly techniques are also advancing in the areas of powder metallurgy, precision die casting and forging, lightweight metal web casting, superplastic forming, and diffusion bonding. Powder metallurgy uses highly-engineered powders at high pressure to form precision metal parts that do not require machining. Powder metallurgy permits use of superalloys developed for high temperature service and severe mechanical stressing with high surface stability. Use of cast metal web parts is currently limited by Federal regulations, which apply a safety margin to cast parts that increases their weight. Superplastic forming produces large changes in the shape of material under conditions of high temperature and low pressure. Diffusion bonding joins parts at high temperature and pressure without melting, because metal atoms diffuse across the solid surface.[32]

New types of materials will be used in propulsion systems and airframes of subsonic aircraft primarily to gain fuel efficiency. Composite materials are already used in some large commercial aircraft, including the Boeing 757 and 767 in ailerons, rudders, and certain landing gear doors, although not for any critical structures.[33] For supersonic aircraft, advanced materials will be used where the aircraft surface reaches high temperature and in propulsion systems for weight reduction and resistance to high temperatures.[34]

Research is under way to examine the implications of using advanced materials for crashworthiness;[35]

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[28] John T. Merrifield, "NASA/Douglas Team Studies Fly-by-Wire Control Concepts," *Aviation Week & Space Technology*, Oct. 27, 1986, p. 38.

[29] *Aviation Week & Space Technology*, "DARPA's Pilot's Associate Program Provides Development Challenges," Feb. 17, 1986, p. 45.

[30] John T. Merrifield, "AI Research at Ames Focuses on Increased Crew Effectiveness," *Aviation Week & Space Technology*, June 2, 1986, p. 73.

[31] Morris A. Steinberg, "Materials for Aerospace," *Scientific American*, October 1986, pp. 67-72.

[32] Pierre Condom, "Forming Aircraft Structural Components: A Slow Revolution," *Interavia*, vol. 41, December 1986, pp. 1429-1430.

[33] U.S. Congress, Office of Technology Assessment, *New Structural Materials Technologies: Opportunities for the Use of Advanced Ceramics and Composites—A Technical Memorandum* (Springfield, VA: National Technical Information Service, September 1986).

[34] Steinberg, op. cit., footnote 31.

[35] Edward H. Phillips, "NASA, Army Testing Composite Airframe Crashworthiness," *Aviation Week & Space Technology*, Sept. 28, 1987, p. 61.

continuing this type of research is important to ensure that FAA has sufficient knowledge to regulate the materials for safe use and maintenance. Composite materials bring a set of unique properties, such as vulnerability to impact, where surface inspection cannot detect subsurface delamination, and new technologies for inspection will be needed. The proliferation of these new materials will require the certifying and inspecting agency to have considerable expertise in their properties at its disposal, and at present FAA has one National Resource Specialist in nonmetallic advanced materials and one in fracture mechanics and metallurgy.

New Aircraft Engine Types

Turbofans are the engines used in most commercial jet aircraft today. While improvements in materials and computer modeling design techniques will allow more efficient turbofans to be built, ultra-high bypass (UHB) engines are likely to surpass turbofans by sometime in the 1990s. Current UHB engines are limited to speeds under Mach 0.80 and therefore require further development for long-range applications. (The Boeing 747, for example, currently flies at speeds of Mach 0.84 to 0.85 where Mach 1 is the speed of sound—about 660 mph at cruise altitudes.) Advanced, high-speed propellers in UHB engines improve the fuel efficiency of the propulsion system by as much as 25 percent compared to current turbofans, potentially cutting by as much as 10 percent the direct operating costs of airlines.[36]

UHB engines raise safety concerns in areas such as bird strike and icing effects, while their external propellers pose potential safety hazards because of the possibility of penetrating fuselage, flight controls, or critical components in case of a malfunction. This problem is partially mitigated by the relatively light weight of the small blades—one manufacturer has developed UHB engine blades weighing only about 10 pounds each. Other safety-related aircraft design features may include separate routing of connections to the aircraft's tail structure and locating the cabin's aft pressure bulkhead forward of the blades' plane of rotation to prevent rapid decompression in the event of blade penetration.[37]

The more distant future may bring new types of engines for use in supersonic and hypersonic aircraft. (Hypersonic refers to speeds five or more times the speed of sound in air.) The turboramjet engine is being studied for hypersonic application. This type of engine would operate as a turbofan for speeds up to Mach 3.5 and as a ramjet at higher speeds. Problems with the turboramjet engine include noise and the need to use endothermic fuels which can absorb thermal energy from the surface of the aircraft produced by aerodynamic heating.[38] For speeds above Mach 6, the supersonic combustion ramjet (scramjet) is being investigated by NASA and others.[39]

Advanced high-speed aircraft include supersonic and hypersonic aircraft. Past experience with high-speed aircraft includes the Concorde and Supersonic Transport (SST) programs. The Concorde was developed by the British and French during the 1960s and 1970s. During the development cycle, sales estimates for Concorde ranged between 100 and 500, but only 16 Concordes were actually built, at a loss of over $3 billion. Although the Concorde was an economic failure, some technology was transferred to other aircraft projects, particularly the French Mirage fighter airplane.[40]

The SST program was undertaken in the United States in 1963 and terminated in 1971, after a total expenditure of about $1 billion. Sales estimates during the program were originally from 25 to 125, and swelled to over 800 at one point, but no aircraft were built. The basic reasons for termination concerned the noise and alleged health consequences of the SST, the social implications of a taxpayer-funded project to benefit only a few well-off people, and technical difficulties: cost estimates by 1971 had grown considerably beyond the original estimates.[41]

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[36] *Aviation Week & Space Technology*, "Ultra-High Bypass Engines Will Enter Commercial Service by Late 1990s," Mar. 9, 1987, p. 189.

[37] *Aviation Week & Space Technology*, "No. 2 UDF Engine Prototype Will Fly on MD-80 by June," Apr. 13, 1987, p. 58.

[38] Paul Proctor, "Advanced Fuel Systems Crucial to High-Speed Transport Progress," *Aviation Week & Space Technology*, Feb. 9, 1987, p. 45.

[39] Raymond S. Colladay, associate administrator, Office of Aeronautics and Space Technology, National Aeronautics and Space Administration, testimony before U.S. Congress, House Committee on Science and Technology, Subcommittee on Transportation, Aviation and Materials, July 24, 1985.

[40] U.S. Congress, Office of Technology Assessment, *Impact of Advanced Air Transport Technology: Part 1, Advanced High-Speed Aircraft* (Springfield, VA: National Technical Information Service, April 1980).

[41] Ibid.

Since the SST, there have been many advances in computers for wing design, and materials and propulsion systems, which have given impetus to further R&D in hypersonic aircraft, although primarily for military application. The National Aero-Space Plane (NASP) project is a joint DoD/NASA program to develop a research aircraft with hypersonic cruise and single-stage-to-orbit capabilities. NASP is currently in a conceptual stage, and speeds up to Mach 25 are projected. Applications that could be developed out of the NASP include strategic reconnaissance aircraft, a replacement for the space shuttle, and civil hypersonic transport aircraft.[42]

NASA has also sponsored studies to examine the viability of SST aircraft around the year 2000. The studies suggest that transports in the speed range of Mach 2 to Mach 6 may be commercially viable, but there appear to be diminishing productivity returns at Mach numbers greater than six.[43]

Technical problems with supersonic aircraft include takeoff noise and sonic boom, possible depletion of the ozone layer, and their very high specific fuel consumption at low speeds. They could not be kept cost-effective for very long in holding patterns at low speed because of high specific fuel consumption and because the value of supersonic travel would quickly dissipate. Capacity problems at many U.S. airports along the coasts are already severe, and may worsen, so airport delays may seriously reduce the advantages of supersonic travel. Also, noise is a major issue with many citizens who live near airports, and is likely to remain so. For all these reasons, the future of commercial supersonic transportation is very uncertain.

Vertical takeoff and landing (VTOL) and short takeoff and landing (STOL) aircraft offer the possibility for landing in and taking off from downtown areas of cities, if appropriate sites can be found at reasonable cost. Passengers on the V/STOL aircraft could be transported directly to their final destination, or to a remote airport for a flight on a subsonic or supersonic airliner. The helicopter is one example of a V/STOL aircraft, but its current speed and fuel efficiency limitations prevent economic use for routine passenger service. Efforts to improve on the basic helicopter design to provide high-speed V/STOL travel has resulted in two practical designs: the tilt-rotor and the X-wing. Both designs are in R&D for military applications with civilian certification criteria in mind.

The tilt-rotor aircraft is a winged aircraft with two large rotors on the wings that can tilt to either a helicopter position for takeoff (with a horizontal plane of rotation) or a fixed-wing position for cruising (with a vertical plane of rotation). DoD is funding development of the V-22 Osprey tilt-rotor aircraft for military application. Six European companies have begun preliminary studies of a tilt-rotor aircraft for civil applications called Eurofar. Tilt rotors have been flown before, and the main technological problem with commercial application is providing improved performance and reduced weight. Some projections indicate that a market for tilt-rotor service exists in the Northeast United States, and service could begin as soon as the 1990s provided that the proper infrastructure is in place to support the operations.[44]

The X-wing aircraft accomplishes vertical or short takeoff with helicopter blades, and uses the blades as an X-shaped wing when cruising. The blades must stop in order to cruise, and the conversion from takeoff to cruise configuration has not yet been mastered. The X-wing concept is under development by Sikorsky Aircraft, following R&D by NASA, the Army, and Sikorsky, and the first flight of a demonstrator could take place around 1990. If successful, the X-wing aircraft could achieve higher cruising speeds than the tilt-rotor.[45]

If used commercially, V/STOL aircraft would fly across the centers of cities, so safety and reliability considerations are especially important. Specifically,

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[42] John D. Moteff, Congressional Research Service, The Library of Congress, "The National Aero-Space Plane Program: A Brief History," issue brief 88-146 SPR, Feb. 17, 1988.

[43] Louis J. Williams, National Aeronautics and Space Administration, "High-Speed Civil Transport Study Status Report," briefing document, n.d.; Boeing Commercial Airplane Co., "High-Speed Civil Transport Studies Phase II Oral Report," briefing document, Mar. 17, 1988; McDonnell Douglas, "High-Speed Civil Transport Studies NASA Contract NAS1-18378 Phase II Summary Review," briefing document, Mar. 17, 1988.

[44] Hoyle, Tanner & Associates, Inc., "VTOL Intercity Feasibility Study," prepared for The Port Authority of New York and New Jersey, July 1987.

[45] *Aviation Week & Space Technology*, "NASA Rotor Systems Research Leads to X-Wing VTOL Aircraft Design," June 2, 1986, p. 22; and Steven Ashley, "X-Wing Aircraft," *Popular Science*, July 1987, p. 48.

Photo credit: Federal Aviation Administration

The XV-15 tilt rotor technology demonstration aircraft has been flying successfully since 1977.

transmission systems of tilt-rotor aircraft must be extremely reliable, since a transmission failure could cause a catastrophic desynchronization of the rotors, at least in the context of current design thinking. Public acceptance of new V/STOL concepts in terms of safety will be necessary for their success.[46]

Technologies and Training for Icing

Since 1975, four fatal Part 121 accidents have occurred in which aircraft icing during takeoff has been a major causal factor. Thus, improvements in detecting and removing aircraft ice prior to takeoff have a potentially great safety payoff.

With the exception of analyses and testing to ascertain flight characteristics of an aircraft during flight, all analyses and aircraft certification testing required by FAA are conducted with a clean aircraft flying in a clean environment. Thus, current certification procedures do not require tests for airworthiness of an aircraft with ice on its surface prior to takeoff.[47] FAA regulations do not require use of any de-icing technology before takeoff, but forbid takeoff when frost, snow, or ice is adhering to the wings, control surfaces, or propellers of the aircraft.[48] (Part 135 regulations also forbid takeoff when frost, snow, or ice adheres to a number of other surfaces.) In general, U.S. carriers rely on pilots to observe their own aircraft for signs of adhering ice. FAA has published advisory documents that provide guidance to airlines and pilots on the icing phenomenon, on technologies for ice removal, and on estimated safe holdover times for aircraft that have been de-iced.[49] Additional basic and recurrent training for pilots is a relatively low-cost method for helping prevent icing accidents. FAA is beginning efforts to enhance training programs for pilots through media such as video presentations.

For roughly 15 years, some European airlines have successfully used more viscous de-icing fluids than those used in the United States; these are called Association of European Airlines (AEA) type-II fluids. Longer-lasting than fluids used in the United States, they are fragile and must be handled carefully to avoid destroying their desirable characteristics. They stick readily to aircraft surfaces and may interfere with the aerodynamic characteristics of the aircraft. AEA type-II fluid is, however, designed so that its viscosity breaks down with shear force, so that the movement of the aircraft tends to knock off the fluid. Because humidity/temperature trends in the United States differ from those in Europe, U.S. airlines might not be as successful as European airlines with type-II fluids; U.S. operators would need time to learn to use type-II fluids effectively.[50]

Despite these limitations, Federal Express has recently begun using the type-II fluids in its aircraft operations. FAA does not plan to develop more specific regulatory guidelines on de-icing technologies, and regulations requiring use of high-viscosity de-icing fluids would impose large costs on airlines and providers of de-icing service for new equipment, operational procedures, and training. FAA regulations might discourage development of more advanced types of de-icing fluid, which would not meet the requirements of the regulation, and other actions can be taken to address icing problems.

Most U.S. airlines de-ice aircraft from trucks at departure gates, after which the aircraft must taxi to the runway entrance and may be delayed waiting for other aircraft to take off. If ice forms on the aircraft during this time, the pilot must taxi back to the gate for de-icing again. At several foreign airports, including Montreal, fixed-base facilities have been set up near the end of a runway to permit de-icing nearer to the time of intended takeoff. One U.S. airline has a fixed-base de-icing facility at Denver Stapleton Airport. Operation of fixed-base facilities in the United States could be limited by liability concerns—most large U.S. airlines do their own de-icing and so do not now have this problem. Such facilities, if their use were mandated, could also limit traffic flow at congested airports.

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[46] Marc Granger, "For or Against the Tilt-Rotor? Two Views of the Enrofar Project," *Interavia*, vol. 42, June 1987, pp. 649-650.

[47] U.S. Department of Transportation, Federal Aviation Administration, "Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing," Advisory Circular 20-117, Dec. 17, 1982.

[48] See 14 CFR 121.629, 135.227, and 91.209 (Jan. 1, 1987).

[49] U.S. Department of Transportation, Federal Aviation Administration, op. cit, footnote 47.

[50] Richard Adams, national resource specialist for Aircraft Icing, Federal Aviation Administration, personal communication, Feb. 23, 1988.

Another possibility is remote de-icing shortly before takeoff from trucks located near the entrances to runways, already a trend, although many airports are limited by insufficient apron space for de-icing trucks to travel and operate. Federal funds could be allocated from the Aviation Trust Fund to expand aprons near entrances to runways and remote de-icing sites to allow mobile de-icing equipment to move and operate.

Lights installed near the airport surface could help pilots see the surfaces of the aircraft better, and qualified ground personnel could examine surfaces not visible to the pilots. Another approach to reducing the icing hazard before takeoff is to use icing sensors on the aircraft surface. Sensors are available, but they pose problems, because they detect ice only at specific areas on the aircraft surface, and pilots may rely heavily on them without proper training.

Given the many possibilities for addressing the icing hazard, FAA could develop a plan for icing similar to the Integrated Wind Shear Program Plan. The best first step could be a training program for pilots and technicians, developed in cooperation with industry. Technological and infrastructure approaches to reducing the icing hazard could also be evaluated for their impact on safety, cost to government and industry, operational factors, and time to implement.

Crash and Fire Safety Technologies

Advances have been made in recent years in developing and implementing technologies to reduce risk to passengers in the event of a crash or in-flight fire. Some technologies, such as smoke hoods, are controversial because their use could have unintentional negative side effects for safety (e.g., putting on smoke hoods could slow passengers' egress from the cabin after a crash).[51] Thus, careful research by the Federal Government is needed to evaluate potential crash and fire safety technologies; this research is performed at FAA's Technical Center in Atlantic City, New Jersey.

Areas for further investigation include aircraft and aircraft engine structural integrity, improved fire- and smoke-resistant materials for aircraft interiors, improved smoke detection and fire containment systems (particularly for in-flight fires), automated systems to aid pilots in detecting and responding to in-flight fires, and advanced fuels with low flammability.

Although technology can improve crash and fire safety, regulations requiring these technologies will have economic and other effects on aircraft manufacturers, airlines, and passengers. For example, the FAA rule to require cabin materials in transport category aircraft that meet a test criterion based on heat release[52] will have significant impacts on design and construction of aircraft interiors. Cost-benefit analysis can shed light on difficult decisions regarding regulations for crash and fire safety technologies, but other types of judgment are necessary in balancing the many disparate considerations.

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[51] Bron Rek, "Escape From Burning Cabins: Are Smoke Hoods the Answer?" *Interavia*, vol. 42, January 1987, pp. 37-38.

[52] 51 *Federal Register* 26206 (July 21, 1987).

CONCLUSIONS AND POLICY OPTIONS

FAA has occasionally attempted to push industry to develop and/or implement new safety technologies. The point at which a new technology is ready for implementation is inevitably subject to a good deal of disagreement. At times, government requirements can act as a forcing mechanism on industry to develop or implement new technology that will lead to greater public safety.

As the aviation industry continues to undergo technological advances and changes, FAA needs adequate numbers of expert technical personnel and training capabilities for new staff not currently available to it, because funding resources are not sufficient to attract trained experts from industry. FAA programs such as Project SMART and National Resource Specialists are steps to address this issue. The future will bring new and increasingly sophisticated commercial aviation technologies, many of which will be introduced not for the sake of safety, but for the economic benefits they promise. However, many hold the potential for decreasing accident risk. **OTA finds that, in the long term, FAA will need greater expertise on its staff in areas of new aviation technology to provide oversight comparable to today's. Congress may wish to consider making additional funding available to bolster FAA's technical staff.**

Part 135 regulations have weaker minimum instrument and equipment requirements than Part 121. This is significant because, since deregulation, Part 135 operations have replaced Part 121 operations over some routes, and code-sharing arrangements have created situations where passengers are not aware they will be flying on a Part 135 operation. One policy option is to eliminate the differences between Parts 121 and 135; however, the economic consequences for Part 135 operators could be serious. Another option is to attempt to identify specific hazards in Part 135 operations, and to rectify the most serious hazards through cost-effective measures as part of overall system safety management.

Aircraft icing before takeoff is an important weather hazard. Better training for pilots and technicians appears to be the most cost-effective near-term approach for reducing the icing hazard to aircraft before takeoff. **For the longer term, greater use of advanced de-icing fluids and de-icing facilities located near the entrances to runways offer possible improvements, but the economic and operational consequences of using these technologies need to be weighed carefully.** The Aviation Trust Fund could be tapped to support construction of wider aprons on runway ramps which would help facilitate use of de-icing vehicles near entrances to runways. **Sensors for detection of ice on the aircraft is another approach, but has operational liabilities if pilots rely too heavily on them.** FAA has begun to increase industry awareness of icing problems through bulletins and advisory circulars. An additional option is for FAA to work with industry to develop an integrated plan for training and other improvements in icing safety. **FAA's integrated windshear plan, with its heavy participation from many industry groups, is a good model for this option.**

Appendixes

Appendix A

List of Acronyms

AAS —Advanced Automation System
AAT —Associate Administrator for Air Traffic
ACARS —ARINC Communications Addressing and Reporting System
ACAS —Air Carrier Analysis System
AD —Airworthiness Directive
ADA —Airline Deregulation Act
ADAP —Airport Development Aid Program
AEA —Association of European Airlines
AERA —Advanced En Route Automation
AI —artificial intelligence
AIDS —Accident/Incident Data System
AIROPS —Air Operator Data System
ALPA —Air Line Pilots Association
ARINC —Aeronautical Radio, Inc.
ARTCC —Air Route Traffic Control Center
ASAS —Aviation Safety Analysis System
ASDE —Airport Surface Detection Equipment
ASRP —Aviation Safety Reporting Program
ASRS —Aviation Safety Reporting System
ATC —air traffic control
ATD —advanced training device
ATCRBS —Air Traffic Control Radar Beacon System
ATIS —Automated Terminal Information Service
AVN —Aviation Standards National Field Office
AVS —Aviation Standards
CAA —Civil Aeronautics Authority
CAB —Civil Aeronautics Board
CAMI —Civil Aeromedical Institute
CERT —Computer Enhanced Radar Training
CRM —cockpit resource management
CRS —computerized reservation system
CWSU —Center Weather Service Unit
DER —Designated Engineering Representative
DOT —U.S. Department of Transportation
DYSIM —Dynamic Simulation
EIS —Enforcement Information System
FAA —Federal Aviation Administration
FAR —Federal Aviation Regulation
FSF —Flight Safety Foundation
FSS —Flight Service Station
GA —general aviation
GAO —U.S. General Accounting Office
GOES —Geostationary Operational Environmental Satellite
GPWS —Ground Proximity Warning System
HF —high-frequency
IFR —instrument flight rules
ILS —Instrument Landing System
IOP —input/output processor
LLWAS —Low Level Windshear Alert System
LOFT —line-oriented flight training
LPP —labor protective provisions
MAC —Military Airlift Command
MLS —Microwave Landing System
MTMC —Military Traffic Management Command
NAS —National Airspace System
NASA —National Aeronautics and Space Administration
NASP —National Aero-Space Plane
NASPAC —National Airspace System Performance Capability
NATA —National Air Transportation Association
NATI —National Air Transportation Inspection Program
NMAC —near midair collision
NTSB —National Transportation Safety Board
NWS —National Weather Service
OMB —Office of Management and Budget
OSI —Open System Interconnection
OST —Office of the Secretary of Transportation
PC —personal computer
PMI —Principal Maintenance Inspector
R&D —research and development
RAA —Regional Airline Association
RSPA —Research and Special Programs Administration
RTCA —Radio Technical Commission for Aeronautics
SAE —Society of Automotive Engineers
SDRS —Service Difficulty Reporting System
SST —Supersonic Transport
STOL —short takeoff and landing
TCA —terminal control area
TCAS —Traffic Alert/Collision Avoidance System
TDWR —Terminal Doppler Weather Radar
TRACON—Terminal Radar Approach Control
UHB —ultra-high bypass
VFR —visual flight rules
VHF —very-high frequency
VTOL —vertical takeoff and landing
WPMS —Work Program Management System

Appendix B

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[1] This list includes Federal Aviation Administration office directors and supervisors; many others in the agency also provided information.

Related OTA Reports

- *Review of the FAA 1982 National Airspace System Plan.*
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  NTIS order #PB 83-102 772.
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